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THE PRINCIPLES INVOLVED IN THE CONSTRUCTION OF THE TELESCOPE.

By THOMAS NOLAN, B. S.

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III.

(4.) DOUBLE REFLECTION.

When the curvatures of the inner surfaces of the glasses of an achromatic lens are such that they exactly fit each other, they are frequently joined together with a transparent balsam, so as to diminish the loss of light in passing through the lens. Whenever light falls upon transparent glass, between 3 and 4 per cent. of it is "reflected back," and when, after passing through, it leaves again, about the same amount is "reflected back" into the glass. Consequently, about 7 per cent. of the light is lost in passing through each lens. By joining them with castor-oil or balsam, the reflection from the second surface of the flint, and the first surface of the crown is very much diminished, and the loss of about 6 per cent. of the light is avoided. In case there is no balsam, the inconvenience of *double reflection* arises. Some of the light "reflected back" from the second surface of the flint, is again reflected from the first surface of the crown, and sent down to the focus of the telescope with the direct rays. If one of the lenses be displaced in the slightest degree, the reflected rays will come to a different focus than the direct ones, and every bright star, for instance, which is viewed with the instrument, will seem to have a small companion star along-side of it.

2. THE EYE-PIECE.

We have thus far discussed the optical principles which are applied in the construction of refracting and reflecting telescopes, consisting of an object-glass or speculum and an eye-piece of the simplest form, viz: a single double-convex lens. We will now go into detail somewhat on the subject of eye-pieces, and explain some of the different kinds.

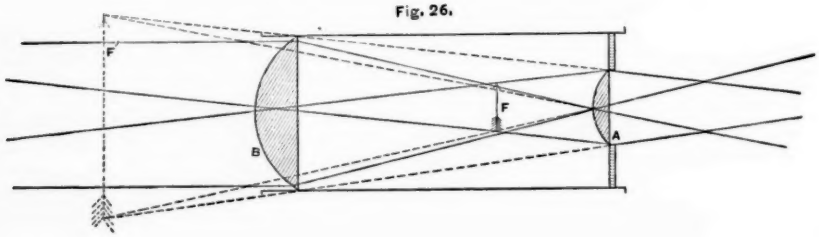
Every ordinary lens possesses the disadvantages of both chromatic and spherical aberration, which have been discussed in connection with the objective. But the eye-piece is not corrected for these errors, in the same way that the objective is. In the case of the former, the errors are corrected by using two lenses of such focal lengths, or at such a distance apart, that each counteracts the defects of the other. We do not use two kinds of glass as in the case of the objective, but so arrange the lenses, that the colored rays produced by the first lens shall fall at different angles of inci-

dence on the second, and thus become recombined.

(1.) THE HUYGHENIAN EYE-PIECE.

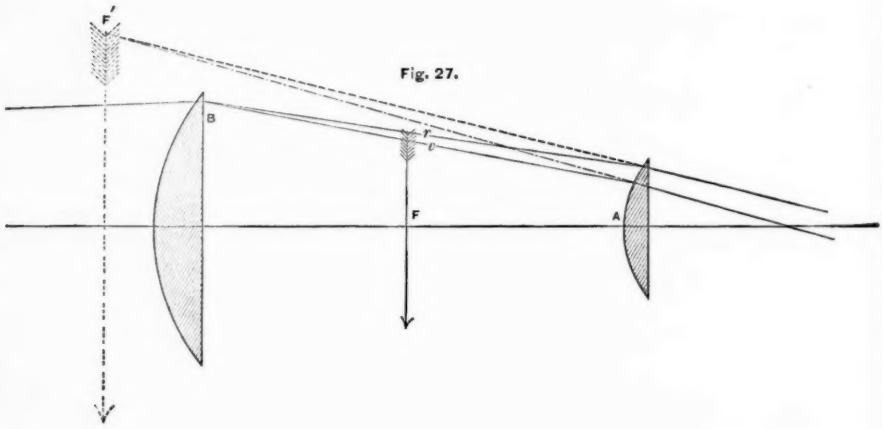
This eye-piece consists of two plano-convex lenses A and B (Fig. 26), with

Fig. 26.



their convexities turned towards the object-glass, and having their focal lengths in the proportion of 3 to 1. The strongest lens, A, is next the eye, and B is placed inside the focus of the object-glass and brings the image to a

Fig. 27.



focus at F, about halfway between A and B. This image is then viewed by A, and a magnified image of it is seen at F'. To show how this combination is achromatic, let us consider the path of a ray falling on the lens near B (Fig. 27). It is there refracted, but as the violet rays are refracted more than the red, there are two rays produced, r and v, giving a colored edge to the image. But when this image is viewed by A, it no longer appears colored, for v, falling nearer the axis of A, is less bent than r, and they are rendered nearly parallel and appear to proceed from the point F', where the image appears without color. The focal length of B is three times that of A, and they are placed at a distance of half their joint focal length apart.

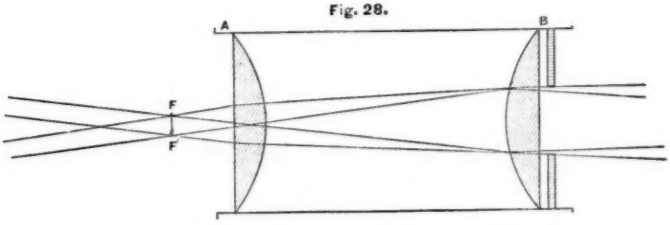
(2.) THE RAMSDEN EYE-PIECE.

The Ramsden eye-piece consists of two

plano-convex lenses, A and B (Fig. 28), of the same focus, placed at a distance of two-thirds the focal length of either apart. They are both on the eye side of the focus of the object-glass, and act together to render the rays parallel, and give a magnified virtual image of FF′. This eye-piece is not strictly achromatic,

Other forms of eye-pieces might be mentioned, as the *Panc*ratic *Eye-piece*, the different forms of *Solar Eye-pieces*, etc., but the various forms, which have been described, are sufficient to illustrate the general principles involved in the construction of those most commonly used for astronomical investigations.

Fig. 28.



but suffers least of all from spherical aberration, and has the advantage of being placed behind the focus of the object-glass, which makes it superior to others in instruments of precision.

(3.) THE ERECTING, OR DAY EYE-PIECE.

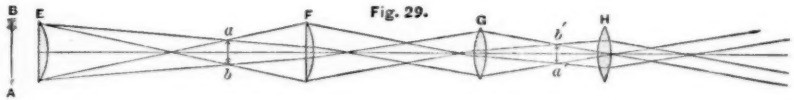
The eye-pieces, which we have described, give an inverted image of the object, that is, they do not right again the inverted image formed by the object-glass. Fig. 29 is a diagram of an erecting eye-piece due to Rheita, and called by his name. It is merely a second application of the same means that first inverts the object AB, viz; a second small telescope. Dolland substituted an Huyghenian eye-piece for the eye-lens H, and so made what is called "Dolland's Four Glass Eye-piece."

IV. COMPARISON OF REFRACTING AND REFLECTING TELESCOPES.

A word or two remains to be said in regard to the relative advantages and disadvantages of the two classes of instruments. The question arises, To which class will the great telescope of the future probably belong? Will it be a refractor or a reflector? In treating of the question of the future of the telescope, many authors have encroached upon the domain of opinion, and have gone beyond the facts vouched for by evidence. But in a discussion of this kind there are three questions to be borne in mind. Of the two classes of instruments:

1. Which has the greater "*light-grasping*" *power?*

Fig. 29.



2. Which is more generally *suitable for observatory work?*

3. Which has greater *permanence of optical qualities?*

In regard to the *first question*, it is certain that up to the present limit of size produced, the refractor has the advantage. But in the reflector, the reflecting power of each unit of surface is constant, whatever the size of the speculum, and in the refractor the transmitting power decreases with the thickness of the glass, rendered necessary by increasing size. It is obvious then, that on increasing the size, a stage must be at last reached, when the two become equal to each other. The limit has been estimated to be 35.435 inches, a size not yet reached by about 9 inches. But object-glasses are slowly gaining in size, and it is not improbable that this limit will sometime be reached.

Suitability for observatory work, depends somewhat upon the nature of the work required. For measuring positions, where permanency of mounting is of great importance, the refractor has decidedly the advantage, whereas, for physical astronomy, where a steady image for a time only is required, it may be found that the advantage will be on the side of the future great reflector.

The *question of permanence of optical qualities* is worthy of attention, and here again, the refractor undoubtedly has the advantage. It is very rarely the case that the polish of object-glasses is in any way injured even after many years of continuous use; while specula, whether of metal or of silvered glass, become considerably tarnished after a few years of service.

After considering these advantages and disadvantages of the two classes of telescopes, we are led to the following conclusions:

1. At the present day the largest refractor is equal in optical power to the largest reflector. It is more convenient in use, easier to manage, and better adapted to general observatory work. And it enjoys a greater permanence of optical qualities.

2. The reflector will be the great telescope of the future if, (1) specula of large diameter can be produced, free from imperfections of curvature and polish; and if, (2) increasing difficulties of mounting and manipulation can be overcome. If these latter mechanical difficulties cannot be entirely removed, the refractor will continue to be the "working instrument" in the future, as it has been in the past, although the future reflector may accomplish the grandest results in the domain of Physical Astronomy.

ON THE EMPLOYMENT OF TORPEDO BOATS AGAINST SHIPS.

By LIEUTENANT CHABAND ARNAULT.

Translated from the "Révue Maritime et Coloniale."

At the end of an article published in the *Révue*, for May, 1874, entitled, "Heavy Guns, Armor Plating and the Ram, in Naval Engagements," we wrote the following lines: "We leave aside the torpedo, because it has never yet figured in engagements between ships, and we wish to argue, not on the results of experiments, more or less conclusive, made in time of peace, but solely on the results of war during the last ten or fifteen years." The Turco-Russian War, which has just been concluded, has given us now the means of applying a similar process to the study of torpedo warfare, employed, not, it is true, as a weapon by sea-going ships, but simply as an engine of destruction used by small steamboats. Relying on the Russian reports M. le Commandant Chardonneau has published, in the *Révue*, very interesting accounts of the principal naval actions fought by the boat-torpedoists of the Czar's fleet. It is a matter of great regret that we are unable to study the account of the same occurrences in the official reports

addressed to the Turkish Government.* We have, however, obtained some information from the latter source, which we shall not fail to make use of. Besides these, the Civil War in America offers two or three naval engagements in which torpedo boats played an important part; we give the particulars of these, before describing those to which the Turko-Russian War gave rise.

Our work is thus divided into two parts: the first consists of the recital of the bare facts useful for us to know; in the second we shall endeavor to throw some light on the lessons which may be drawn from them.

I.

(I.) The destruction of the "Houssatonic," on the night of the 17th February, 1864. In the course of the year, 1863, the Confederates built several boats, taking more or less the cigar form, and known in America by the name of "Davids." These boats were intended to attack the Federal vessels with spar torpedoes. One of them, built at Charleston, had the power of sinking herself completely at the moment of attack. Her propeller was a screw, worked by hand, by a crew of eight men. During her first cruize, under the orders of Lieutenant Payne, an enemy's vessel passed close to her without noticing her; the swell raised by the paddles of this craft sank the "David," and Payne alone, of all the crew, saved himself. This intrepid officer did not lose heart, and he persuaded eight sailors to follow him again in his boat when she was recovered. A squall of wind produced an accident similar to the former one. Payne and two blue jackets escaped death. The boat, again picked up, had some novel experiences. At the intended moment she dived, but never came up again, and Payne perished this time with all his crew. And even after three such catastrophes, a Lieutenant Dixon was able to find eight men sufficiently devoted to man the same boat when she was fished up from the bottom of the River Cooper!

"On the 17th February," writes the author of several interesting remarks on the Civil War, "the Federal corvette "Houssatonic" was at anchor off Charleston, on the outer line of the blockade; it was dark when, about 8.45 P. M., the officer of the watch perceived something moving in the water towards the ship, about 100 yards distant. It came straight towards the ship, and in two minutes was alongside. During this time the cable was slipped, the engines moved astern, and the crew called to quarters. About one minute later the explosion took place, and the ship, going down by the stern, heeled over to port, and sank. Happily the weather was fine and the water shallow. The crew, with the exception of two officers and some men who were drowned, saved themselves in the rigging, and were rescued by the boats of the 'Canandaigua.'"

It was the heroic Dixon who thus inaugurated, in naval engagements, the *role* of the torpedo carried at the end of a spar. His submarine boat disappeared with all its crew.

(II.) Unsuccessful night attack on some Federal frigates. "Other unsuccessful efforts," continues the author whom we have already quoted, "were made by the Confederates against the men-of-war of the Union. The first was directed against the ironclad frigate 'New Ironsides,' by a rebel Lieutenant, who, in a small cigar-shaped boat, proceeded to attack her in the middle of the night, when off Charleston. Although he got alongside without being discovered, and although the explosion was effected, there was no further damage done than the death of the officer of the watch of the 'Ironsides,' and the loss of the torpedo boat, which was sunk by the mass of water thrown up by herself. The frigates 'Minnesota,' 'Wabash' and 'Memphis,' were successively attacked by cigar-shaped torpedo boats, but they escaped, owing to the watchfulness of those on board."

(III.) Destruction of the "Albemarle" (night of the 27th October, 1864).—Towards the close of the year 1864, the town of Plymouth, on the River Roanoke, was in possession of the Confederates, but besieged by the Federal troops. A Confederate ram, the "Albemarle," defended it against all attacks from the river side. This vessel was se-

* Though no official Turkish reports have been published, Hobart Pasha, commanding the Turkish Fleet in the Black Sea, has printed in vol. cxxvii. of the *North American Review*, 1878, some notes on the occurrence in the late war. His statements differ very much from the Russian accounts.—Ed.

cured to a quay, under the double protection of a battery of guns and a stockade of floating branches of timber, which formed a circle about ten yards from her. A young officer of the Federal navy, Lieutenant Cushing, volunteered to attempt the destruction of the "Albemarle" by means of a boat fitted with a spar torpedo. On the night of the 27th October, he ascended the Roanoke, and was received, on approaching the ram, by a brisk fire of musketry; his boat, however, going at full speed, struck on the stockade. Cushing himself worked the movable spar of his torpedo, placed it beneath the side of the "Albemarle," and fired it by means of a friction tube. The explosion, or perhaps a shot from the ram, sank the Federal boat, but the "Albemarle" went down almost immediately, and Lieutenant Cushing, who saved himself by swimming, succeeded in rejoining the Federal army through the woods.

Such were the several very noteworthy engagements which gave rise, during the American war, to the employment of torpedoes as offensive weapons by boats. We shall now recount the similar acts which signalized the last war between Russia and Turkey.

At the commencement of hostilities the Turks had, on the Danube, 3 monitors, 5 ironclad gunboats, and 6 wooden gunboats; in the Black Sea, 2 frigates and 8 ironclad corvettes, besides a certain number of wooden ships. The Russians could oppose no respectable man-of-war to this numerous fleet, but they possessed, in the Black Sea ports, 15 torpedo boats, mostly of the Thorneycroft type, with silent engines, very light and fast, and built in water-tight compartments. A screw-steamer, the "Constantin," handed over to the Government by a maritime Company of Odessa, was arranged to carry, and to hoist up rapidly under massive boomkins, four of these boats. The Russians also launched on the Danube quite a flotilla of torpedo boats, but the majority of these latter were ordinary steam launches fitted with a spar torpedo over the bows.

(IV.) First affair of Batoum (night of 12th May, 1877).—At ten o'clock in the evening, the "Constantin" being seven miles from Batoum lowered her four boats, which immediately steered for the port. On arriving there, the "Tchesme," commanded by Lieutenant Zatzarennyi, was ahead of the other Russian boats by three or four cables' lengths; he was armed with a towing torpedo. Zatzarennyi, observing an ironclad moored at the head of the bay, cleverly manœuvred his boat and succeeded in striking with his torpedo the stern of the vessel. No explosion occurred. We do not know the exact type of the "diverging" torpedo employed by the Russians, but it appears that the towing conducting wire, which was fouled for a moment in the screw of the "Tchesme," suffered a denudation, which prevented the electric current from passing and from lighting the primer. The Turks, however, had taken the alarm, their shore batteries, as well as their ships, opened such a brisk fire of artillery and musketry, that the torpedo boats thought it best to be off with all speed. The "Tchesme" and the "Sinope" reached the neighboring harbor of Poti, the other two boats rejoining the "Constantin."

(V.) Destruction of the "Seife" (night of the 25th May, 1877).—Three Turkish ships were at anchor, with steam up, in the arm of the Danube which passes the town of Matchin, the double-turreted monitor "Seife," an ironclad gunboat, and a wooden ship. No obstructions protected them, but two guard-boats watched them, one at a short distance from the "Seife," the other near the ironclad gunboat. Four Russian torpedo boats, from the neighboring town of Braila, steamed up the Matchin arm to attack the Ottoman squadron. They were ordinary steam launches, whose engines and crew, composed of about a dozen sailors, were protected, with the exception of the man at the tiller, by metallic roofing; each of them being armed with a torpedo carried at the bow, containing a large charge of gunpowder and which could be immersed to a depth of 10 feet, and fired electrically either by contact or by will. The sky was overcast, a slight mist hung about the river, but the night was not very dark. The Russian boats crept along the banks of the river, and as their engines were noisy, they went slowly so as to make as little noise as possible. The Turkish officer, who commanded the "Seife's" boat, perceived them, but lost his head, and

pulled off as fast as possible instead of alarming his compatriots. It was then half-past two in the morning. Arrived within a cable's length of the "Seife," Lieutenant Doubaroff, who commanded the Russian boats, put his boat, the "Czarwitch," at full speed, and was hailed and made out by the Turkish sentries. His torpedo struck the keel of the "Seife" under the overhanging part of the stern and exploded by contact. The "Czarwitch," which the fall of water had three-quarters filled, hauled off as quickly as possible under the fire of musketry from the monitor. The latter began to sink astern, but so slowly that at the end of ten minutes Doubaroff ordered the "Xenia" to attack her. Lieutenant Chestakoff, who commanded this boat, took the "Seife" broadside on, and exploded his torpedo by hand. He experienced some difficulty in getting away, as the screw of the "Xenia" was fouled by some of the *debris* arising from the two explosions. Happily the "Seife," which had only been able to fire two shots, then sank very rapidly until the moment of her disappearance, her brave crew never ceasing to keep up the fire from theirrifles. The other two Turkish ships, slipping their cables, had opened a well-sustained fire of artillery and rifles. A bullet pierced the hull of one of the two boats which had been left in reserve. This boat was obliged to beach herself on the bank, but quickly stopped the leak, and was able to follow the other boats of Doubaroff in their retreat. This fine affair cost the Russians none killed nor wounded.

(VI.) Affair of Sulina (night of 10th June, 1877).—In consequence of the feeling caused by the loss of the "Seife," the Commander-in-Chief of the Turkish fleet, Hobart Pasha, ordered the vessels under his command to observe the following rules: 1st. To keep one watch under arms at their quarters all night. 2d. To constantly patrol, by boats under steam, or, in default of these, by boats under oars, the neighborhood of the vessel. 3rd. To surround the latter by obstacles capable of stopping the advance of a torpedo boat. All these measures of prudence were rigorously observed by the crews of three armored corvettes and a gunboat at anchor before Sulina on the night of the 10th June. The obstacles which surrounded these vessels consisted of ropes, arranged parallel to each other like clothes-lines, stretched between two boats which were kept in their places by strong anchors, and supported at intervals by little buoys, the upper part of this system coming level with the top of the water, though keeping out of sight. The Russians affirm that one of the Turkish ships was under weigh, but the Turks do not mention this circumstance. The ironclad corvette "Idjalick" was anchored at the head of the squadron.

The "Constantin" had left Odessa on the 10th June, with three torpedo boats hoisted to her davits, and three more in tow, and stopped the following night when five miles from Sulina. At half past one in the morning, the boats, divided into two groups, steered towards the port. At their head was the "Tchesme," commanded by Zatzarennyi, and armed with a "diverging" torpedo; their boats Nos. 1 and 2, under the orders of Lieutenants Poustchine and Rojdestoonski. The night was so dark that in spite of the precautions taken by the Turks, the Russian boats arrived within 100 yards of their ships without being observed. Zatzarennyi made a sweep to bring his "diverging" torpedo to bear against the "Idjalick," but his towing-conducting wires fouled the screw of the "Tchesme," and she was obliged from that time to cease taking part in the action.

According to the account of M. Chardonneau, the torpedo boat No. 2 attacked the "Idjalick," whilst No. 1 advanced on another vessel, but all the accounts from Turkish sources agree in pointing out the "Idjalick" as having been the adversary of Lieutenant Poustchine, and besides, none of them say that any other ship had to repulse a Russian attack. It is, therefore, nearly certain that the "Idjalick" was the only antagonist of boats Nos. 1 and 2. The latter, going at full speed, cleared the obstacle round the Turkish ship, and her torpedo exploded on contact; it is probable that it struck some obstacle before touching the bottom of the "Idjalick," or was struck by a projectile which ignited its priming, since this explosion produced no damage to the enemy's ship. The Turks, in their reports, do not even mention it. How-

ever it may have been caused, the water from it filled the fore compartment of boat No. 2, and she, being thus brought down by the head, was able to clear the obstacles and free herself by going astern. For some minutes the Turks had opened a general fire of artillery and musketry, it was then that No. 1, stopped at first by the ropes of the obstruction, succeeded in clearing it. Lieutenant Poustchine was standing by to fire the torpedo himself if contact did not effect it, but the explosion took place in an unexpected manner before the boat's spar touched the enemy's bottom. The "Idjalick" only suffered some slight damages above water. It appeared that, excited by the brisk fire of the Turks, the blue jacket charged with immersing the torpedo had failed in his work; the torpedo was on the surface of the water and was struck by a projectile which exploded it. Lieutenant Poustchine disengaged himself, but his boat had suffered such damages that they were obliged to abandon her, and this brave officer and the six men who accompanied him were kept afloat by their life-belts; at daybreak they were picked up by the Turkish boats.

The second group of Russian torpedo-boats, who had taken no part in the action, the "Tchesme" and No. 2, rejoined the "Constantin," without the loss of a man.

(VII.) Day affair near Rustchuk (20th June, 1877).—With the intention of closing the navigation of the Danube to the Turkish ships, the Russians had adopted the plan of placing lines of mines in several places. On the morning of 20th June, six of their boats were occupied in arranging such an obstacle, near Rustchuk, when a Turkish ironclad from this place obliged them to take refuge amongst the reeds which border the river. The boat "Choutka," armed with a spar torpedo, and commanded by Lieutenant Skrydloff, started at full speed to intercept the course of the Turkish ship, in face of a hail of projectiles which fell around him, but the torpedo would not explode since its conducting wires had been cut in two places by bullets, and at this moment the bow of the "Choutka" was pierced by a bullet or case shot; the boat however, going at full speed, succeeded in escaping. Skrydloff and four of his companions were wounded.

(VIII.) Day affair near Nicopolis (23d June, 1877).—During the course of this day, a Turkish monitor, commanded by an English officer, left Nicopolis and proceeded down the Danube. Two steam boats armed with spar torpedoes waited for her as she passed, hiding themselves behind a little island. They darted at her at full speed. The monitor let fall rapidly round her side nets hung to booms, each one carrying a torpedo at its extremity, opening at the same time a lively fire of artillery and musketry. One of the Russian boats, the "Mina," had the wires of her torpedoes cut, and suffered such damages as obliged her to haul off. The other, the "Choutka,' commanded by Niloff, vainly struggled to reach the hull of his enemy; stopped by the booms and nets, pierced by a splinter of a shell, driven on shore by the monitor, she had great difficulty in saving herself. Although the crews of the Russian boats were protected by screens and iron shields, they had four or five wounded on that day.

(IX.) Affair at Soukhoum Kalé (night of 23d August).—In reading the account of this engagement, which M. Chardonneau has given, we understood that the weapons employed by the Russian boats were spar torpedoes, one of these boats having been, in fact, half filled by the column of water from the explosion, and another sunk on approaching the Turkish ship, circumstances which would seem to indicate a very close attack; but a recent note by M. Chardonneau in the "Révue Maritime," of November, 1878, the report written by Captain Makaroff, of the "Constantin," as well as certain information from Turkish sources, seem to point out that the engines used by the Russians against the "Assar-i-Chefket" were "diverging" (towing) torpedoes.

Profiting by the night of the 23d August, on which there was an eclipse of the moon, the "Constantin" stopped some six miles from Soukhoum Kalé. Some Turkish ironclads frequently moored before this place, which had recently fallen into the hands of the Sultan's troops. The four torpedo-boats of the "Constantin," headed by Lietenant Zatzarennyi, started off with the inten-

tion of seizing the moment of the eclipse to enter the roads of Soukhoum. Towards half-past two in the morning, they perceived a Turkish ironclad at her anchorage. This was the corvette "Assar-i-Chefket," commanded by a brave officer who had served some time in the English navy. Hence there was good watch kept on board this ship, several boats were guarding her, and large fires lit on the shore illuminated all the roadstead. The Russian boats were, in consequence, early received by a lively fire from the "Assar-i-Chefket," and from the batteries of Soukhoum. The "Sinope" and the "Navarino" succeeded, nevertheless, if we are to believe the officers commanding these boats, in exploding their torpedoes against the starboard side of the ironclad; the crew of a Turkish boat, hauled up alongside the "Assar-i-Chefket, was actually engaged for a moment in a hand-to-hand fight with the crew of the "Sinope," using their stretchers for arms. The "Navarino" was half filled with water by the columns from its torpedo. The Russian boats "Tchesmé" and "Mina" had steered towards another vessel, but, on making her out to be a merchant brig, they returned towards the "Assar-i-Chefket." The "Mina" exploded her torpedo against the starboard side of the ironclad, the "Tchesmé" attempted the same manœuvre, but as she approached the "Assar-i-Chefket," the rolling of the latter, caused by the explosion of the "Mina's" torpedo, would have infallibly upset the boat. The Russian boats rejoined the "Constantin" with all speed. This attempt, they say, did not even cost them one wounded. Such is the account of the battle of Soukhoum from Russian sources. The "Assar-i-Chefket," however, only suffered slight damages, since after a stay at Constantinople, from 31st August to 12th September, she proceeded to cruise on the coasts of the Adriatic. Her captain besides affirms that on the night of the 23d August, only one of the torpedoes directed against him was fired, and that the explosion was not even effected when in contact.

(X.) Second affair of Batoum (night of the 27th December).—About ten o'clock in the evening the "Constantin" stopped five miles from Batoum and lowered her four torpedo-boats. The night was perfectly dark, a fine rain was falling, and the sea was only ruffled by a slight swell. Lieutenant Zatzarennyi, who had, as before, the command of the Russian boats, had some difficultly in finding his way in the darkness. However, about midnight he rounded the point of Batoum, and observed two large ironclads lying at single anchor, bows outwards, with their sterns moored to the shore. They noticed round them neither obstructions nor guard-boats. Each of the Russian boats, "Tchesmé" and "Sinope," was armed with a Whitehead torpedo. The former carried her tube under the keel, the latter had hers arranged on a raft which she towed. Arrived at about seventy yards from the nearest Turkish ironclad, the two boats fired their torpedoes almost simultaneously; that of the "Tchesmé" exploded on the beam of the enemy's ship, that of the "Sinope" appeared to strike the stern of the ironclad. Their course would easily be followed on the surface of the water. Not till then did the ships and Turkish batteries open their fire on the Russian boats, which rejoined the "Constantin" with all speed. On the way the "Tchesmé" got rid of her injection tube.

The Turkish ship attacked by the Russians boats had not suffered any serious damage. M. Chardonneau thinks that the "Tchesmé's" torpedo struck a rock, and that of the "Sinope" did not explode. But may we not suppose that the Russian torpedoes exploded against under-water defences arranged by the Turks?

(XI.) Third attack at Batoum. Destruction of a Turkish war ship (night of 25th January, 1878).*—On the 25th January, at half-past eleven at night, Captain Makaroff again stopped five miles from Batoum, and sent off, under orders of Lieutenant Zatzarennyi, the two boats "Tchesme" and "Sinope," each armed with Whitehead torpedoes. The weather was cloudy, but towards two in the morning, the moon rising, enabled the Russians to distinguish perfectly the ships moored before Batoum. One of these was an unarmored cruiser

* According to Hobart Pasha, this never occurred; no ship was destroyed at this time and at this place.—ED.

of 1,200 or 1,500 tons, anchored at the head of the bay. The "Tchesmé" and the "Sinope" steered for her, and when about eighty yards from her beam, simultaneously fired their Whitehead torpedoes. Both exploded, and in less than three minutes the Turkish vessel entirely disappeared. The Russian boats successfully returned to the "Constantin."

II.

When acts of war are studied with the intention of deriving therefrom useful lessons, it is necessary to bear in mind the relative worth of the *personnel* and of the *material* which are employed in each encounter by the two belligerents. A victory gained by forces wisely organized over barbarians without discipline and unpossessed of deadly weapons, proves, from a military point of view, nothing; a success, which the troops or navy of one powerful nation owe to the employment of improved weapons, over adversaries equally powerful, nearly always furnishes examples well worth our consideration. Now, in the case which we are considering, it is certain that during the two last years of the great American War, that is, at the time of the destruction of the "Houssatonic" and of the "Albemarle," both Federals and Confederates possessed sailors, devoted up to the point of heroism, admirably cognisant of the details of their business, and furnished with weapons, often of most recent invention, which were not for that reason less formidable in their hands. We have only described the strange career of the submarine boat, commanded successively by Payne and Dixon, for the purpose of showing to what a pitch certain Americans then pushed their self-devotion.

In the Turco-Russian War, the adversaries whom we find opposed equally merit the most serious consideration. The sailors of the Czar's fleet gave such decisive proofs of their bravery, audacity, and dexterity in handling their torpedo boats that it would be superfluous here to extol their military virtues. Amongst the Turks, courage and devotion were not less remarkable. Recalling the destruction of the "Seife," until the moment when this monitor sank beneath the waves of the Danube, her intrepid defenders remained at their stations, pouring fire on the enemy! The Osmanli have, it is true, the reputation of keeping a bad look-out, but it should not be forgotten that during the later engagements, the Sultan's Navy was commanded by an English officer of the greatest energy, Hobart Pasha, and that several of his ships were manoeuvred by captains of the same nationality If the watch kept was defective at Matchin and in Batoum Roads, it was perfect, nevertheless, at Sulina and before Soukhoum Kale. Thus, on the Danube, as well as in the Black Sea, the Turkish sailors were worthy foemen for the Russians.

This point once established, let us examine the actions which have been recounted. When, for the first time, the Americans employed the torpedo as the offensive weapon of boats, the latter seemed threatened with three dangers, which must inevitably, it was feared, cause their loss; if the direct effect of the "water-blow" did not stave in their bottoms; if the column thrown up by the explosion did not fill them, extinguishing the fires in their boilers, how were they to escape the hail of bullets, case-shot, and balls hurled by a watchful enemy? After the American War, after the destruction of the under-water boat commanded by Dixon, of the steam pinnace of Cushing, and of the "David," which tried to sink the "Ironsides," one certainly considered as sacrificed, beforehand, every torpedo-carrying boat which was despatched against an enemy's ship. Soon, however, numerous experiences came to show that a well-built torpedo boat had nothing to fear from the shock, or from the thrown-up water. The fights at Matchin, Sulina, and Soukhoum Kale thoroughly confirm these opinions. In fact, several of the boats employed by the Russians, especially at Matchin, were far from presenting the guarantees of strength, which the beautiful boats specially constructed for torpedo work of the present day possess; none, however, of them were lost in consequence of the torpedo which they carried. If the under-water boat of Lieutenant Dixon, and the "David," directed against the "Ironsides," were less fortunate, it is only to be attributed to their defective construction. In respect of

Lieutenant Cushing's boat, it seems proved that its loss was caused by a shot from the "Albemarle."

The fire of guns, mitrailleuses, and rifles—these are the only real dangers which the torpedo boats have to fear. Before the Russo-Turkish War, many seamen considered this risk as so serious, as to place in doubt the efficacy of a direct attack by boats armed with torpedoes, not only in the daytime against a vessel under weigh, but even at night against a vessel at anchor, if a good look-out were kept. We may believe now that a torpedo boat, suitably built, does not run any exceptional danger. What, in fact, do the engagements just quoted teach us? Leaving aside boats which did not directly contribute to the results, whose crews, though present on the spot, were not actively engaged, neglecting also the American boats, which were victims only to their defective construction, we see that during the Turko-Russian and American Wars, sixteen torpedo boats attacked enemy's vessels, with torpedoes of different descriptions. Now, of these sixteen boats, only two were destroyed, Lieutenant Cushing's pinnace and Lieutenant Poustchine's boat; the latter officer even avows that he sank the boat himself, as an accident to the machinery, suffered after the engagement, would certainly have caused her to fall into the enemy's hands. Finally, several of the Russian attacks were made under most unfavorable circumstances; at Matchin, the "Xenia" was immovable for ten minutes under the fire of the "Seife," before attacking her; at the engagement at Sulina, boats Nos. 1 and 2, after having cleared the rope obstruction of the "Idjalick," occupied a relatively long time in disengaging themselves; before Soukhoum, the four boats which fought the "Assar-i-Chefket" were made out at a considerable distance by the Turks. But these are nothing compared to the temerity which the Russians displayed during the affairs of Rustchuk and Nicopolis in broad daylight. The officers declare that at the latter of these actions the "Choutka" remained exposed for an hour to the fire of her adversary—a Turkish monitor, well armed and perfectly commanded—and, nevertheless, the "Choutka" succeeded in escaping, just as the "Mina" saved herself, and just as the boats employed at Matchin, Sulina, and Soukhoum Kale escaped.

Some recent experiments have shown that a fast steam launch, when pierced by one or more balls of the size of case-shot, is in no danger of sinking if it continue at high speed. This fact was confirmed, on different occasions, during the Russo-Turkish War. The "Choutka" was pierced at Rustchuk by a tolerably-sized projectile, and at Nicopolis by a grape-shot, and on both occasions kept herself afloat by going at full speed; near Matchin, the Russian boat "Djiguite," of only moderate speed, received a bullet which pierced her stern; she had time, nevertheless, to beach herself, and was able to stop her leak in a few minutes.

Will not the crew of a torpedo boat be more endangered than its hull, under the hail of bullets, grape and case, of the enemy? Examination of the different actions of the Turco-Russian War permits us again to answer this question. Taking, first, the night affairs; one wounded, such is the only loss suffered by the eleven torpedo boats, which, exclusive of the boats themselves destroyed by one means or another, attacked different ships. In the engagements, relatively prolonged at Matchin and Sulina, not a Russian was touched by the Turkish projectiles, and, for all that, several of the boats which Doubaroff and Zatzarennyi led were simply protected by screens, or by half-made roofings.

In each of the two day affairs, at Rustchuk and at Nicopolis, the assailants lost three or four wounded, but there again they were most imperfectly sheltered from the enemy's bullets. It may well be asked by what miracle the "Choutka" and her crew escaped, on the 23rd June, from the continued and prolonged firing of the monitor which they had so pluckily attacked. The artillerymen of the Turkish ships possibly were not very well drilled, but the riflemen have not usually been considered more inexpert than others, and we repeat that some of the Ottoman ships, pre-eminently those commanded by English officers, proved in this war that they were capable of rendering good service.

Hence, and present experience shows it, the attack by day or by night

of a well-built torpedo boat against a vessel at anchor or under weigh does not present exceptional danger, either for the boat herself or for her crew.

In all coast wars, then, the employment of torpedo boats is possible, but will it be really efficacious? The first part of this article has shown us that, out of fourteen attacks made by torpedo boats, four compassed the destruction of the ship, three have caused more or less serious damage to the enemy; the others appear to have been resultless. Now, in each of these affairs, the *materiel* and *personnel* exposed by the assailants to the fire of their enemy were hardly worth mentioning—ten or twenty men and one or more boats, worth together from 15,000 to 100,000 francs. And it was with forces small as these that they succeeded once in three times in destroying a ship manned by hundreds of men, and the cost of replacing which was measured by millions of francs. Is not such a result sufficiently conclusive?

Let us notice also the conditions under which the pre-described attacks were made. The American torpedo boats employed during the war were all, as we have already seen, singularly defective; many also of the Russian boats employed during the last war against the Turks left much to be desired. Have the torpedoes themselves which were employed by the assailants always given sufficient proofs of their efficacy? Not so; for the diverging torpedo of the "Tchesme" would not even ignite in the first affair at Batoum, and was not able to be used at Sulina: again, at Soukhoum the explosion of these torpedoes—probably of a similar description—only caused trifling damages to the "Assar-i-Chefket."

Another question—The Russian crews were excellent, but did they always manoeuvre their torpedo boats in the most judicious manner? During the first affair at Matchin four boats were under the orders of Lieutenant Zatzarennyi, but only one, the "Tchesme," attempted to use her torpedo. This, then, we pronounce, was a very trifling attack. If the boats had together charged the Turkish ironclad which was attacked by the "Tchesme," would the result have been the same? In the Danube, near Matchin, the intention of Doubaroff was to engage successively each of the enemy's ships, only using one boat at a time; from this cause three boats remained stationery for ten minutes under the fire of the Turks. Would it not have been more decisive, and less dangerous, to have attacked simultaneously the "Seife" with the "Czarwitch" and the "Xenia," and the armored gunboat with the two other boats? It is enough to read the account of the fight at Sulina to see that in this case the plan of the Russian officers was badly laid. Alone of all the night attacks made during the last war, those against the "Assar-i-Chefket" and the ship sunk before Batoum, were conducted in a faultless manner.

The affairs of Rustchuk and of Nicopolis deserve special attention. Such an attack, made in broad daylight, against a ship under weigh, has none of the same characteristics as a night attack. In the latter, the object of the assailants is to surprise an immovable vessel; one boat alone is sufficient to obtain the success; the destruction of the "Houssatonic" and the ruin of the "Albemarle" prove this incontestably. In the former case, on the contrary, it is necessary to fight an enemy on his guard, who sees his enemy approaching from afar, and can manoeuvre quickly. Several boats should then unite their endeavors to divide his attention and augment their own chances of success. The attacks of the "Choutka" and "Mina" were therefore almost fatally condemned to failure, for, in an action like that of Rustchuk or Nicopolis, the co-operation of four boats, at the least, seemed necessary.

Thus the torpedo boats of America and of Russia have fought the majority of their actions under circumstances unfavorable to the efficacy of their weapons. This consideration causes the practical worth of an arm to stand forth, the record of the success of which on the field of battle is one overwhelming success to two checks.

We have noticed that in each of the affairs at Rustchuk and at Nicopolis, the Russians suffered the loss of four or five wounded; in nearly all their night attacks, on the contrary, they did not lose a single seaman from the fire of the enemy. This fact quite proves that if ordinary boats may be utilized to surprise a vessel in the midst of darkness, a day

attack requires special boats—fast, turning rapidly, presenting as small a target as possible to the enemy's gunners, and the crew of which should be absolutely protected against musketry. Grape and case can pierce the boat, but the experience gained at Rustchuk and Nicopolis shows us that if the engines remain unharmed, the boat escapes by keeping up a high speed. Hence great lightness of hull, rapidty of movement and turning, small dimensions, musketry protection limited to the machinery and the fighting posts of the crew—such seem to us to be the principal requirements which boats specially built for torpedo fighting should fulfill.

Proceeding with our subject, we will now endeavor to determine what sort of torpedo, according to different circumstances, is best employed in boats.

During the first affair at Batoum, and before Sulina, the "Tchesme" vainly endeavored to use a "diverging torpedo."* If, as we believe, the "Assar-i-Chefket" was attacked by weapons of the same description, the inefficiency of the three explosions on this occasion will singularly enforce the arguments employed against their use. The captain of the Turkish ironclad, we saw, affirms that one only of the Russian torpedoes exploded. There is nothing surprising in this contradiction between the relative accounts of the affair at Soukhoum. In the midst of darkness, of disturbance produced by the repeated discharges of heavy guns and of musketry, the assailants might very well have taken the explosion of a heavy gun for that of a torpedo blowing up, at over forty yards distance from their boat; or those attacked might not even have heard the noise caused by this latter explosion. We do not know what was the exact method of igniting the torpedoes used against the "Assar-i-Chefket," but if we admit the accuracy of the Russian accounts, how are we to explain the inefficiency of the three explosions? Was the Turkish vessel protected by a ring of floating baulks of timber, kept at a slight distance from the hull, and against which the enemy's torpedoes struck and exploded? No report gives any support to this suggestion. From whatever cause it arose, the failure of the diverging torpedoes of the "Tchesme" was sufficient to cause the rejection of these machines from use in boats. It was seen, in fact, that they might become for the assailants a cause of delay and of mischief, spoil the boat's maneuvering, and place her, in a word, in a most critical position under the fire of the enemy. Still, might not all these inconveniences be compensated for by very great chances of efficacy? Certainly not. The slightest floating protection will stop the diverging torpedo. Ropes stretched between two booms will throw off its towline and save the ship from all danger.

Reasoning, therefore, founded on the experience acquired during the Russian War, leads us to reject entirely the employment of divering torpedoes from boats.

The actions which we have described at the commencement of this article present three complete successes out of six attacks made by means of the spar torpedo. But, as we have seen, the torpedo boats employed by the Americans during the war were defective, and also the affairs of Rustchuk and Nicopolis were undertaken under conditions peculiarly unfavorable to the assailants. The destruction of the "Houssatonic" and of the "Seife" show that the spar torpedo is, during the night, a terribly effective weapon against vessels at anchor, unprotected by external defences. That of the "Albemarle" and the fight off Sulina prove that such a defence is sometimes insufficient. We know, in fact, that during the night of the 10th of June the Russian boats of Lieutenants Rojdestoonski and Poustchine cleared the obstacles which surrounded the "Idjalick." That their torpedoes did not destroy this ship was because they were struck by a projectile, or met some obstacle inside the "stockade" arranged by the Turks. However, this stockade was possibly, in fact probably, the chief cause of the failure of the Russians, since it detained them for some minutes under the fire of the "Idjalick," produced amongst them momentary disorder, which prevented them working their torpedoes with all the coolness desirable. Now, however rapidly the torpedo spar may be worked, there must always be

* Evidently some form of Harvey torpedo, to be ignited by electricity.

the greatest difficulty in immersing the apparatus, during the short space of time which the boat occupies in passing over the space which separates the vessel from her defences. In the day affair at Nicopolis it was similarly the nets and booms of the Turkish monitor which presented an impassable barrier to Lieutenant Niloff's boat. Relative powerlessness against a vessel defended by exterior obstacles, then, is the principal objection which can be made to the employment of the spar torpedo.

The Russians attribute the premature explosion of the two torpedoes which they were using against the "Idjalick" to their being struck by a projectile; at Rustchuk the torpedo of the "Choutka," at Nicopolis that of the "Mina," could not be fired, according to the Russian officers, because their wires had been cut by bullets. Should we not rather look for the cause of these four failures in the defects of the weapons employed by the Russians, in the over hurry of their maneuvers, or in some blunders made when under the enemy's fire? In fact, experience proves that the impact of bullets or grape-shot cannot explode a torpedo, unless they act directly on its priming; and, also, two conducting wires are a very small target for musketry; besides, there is nothing to prevent these wires being protected by means of the torpedo spar itself. If we must give absolute confidence to the Russian reports, a most improbable chance brought about, on four different occasions, accidents, which the fallibility of men, even the most practical and the bravest, explains much better. Hence we cannot consider the damage to which the enemy's fire subjects the spar torpedo as a serious objection to their use.

We have only been able, unfortunately, to cite two actions in which the assailants used the Whitehead torpedo; one was a check, the other a complete success for the Russians. What actually occured at that second affair of Batoum? M. Chardonneau believes that the "Tchesme's" Whitehead struck a rock; since this torpedo was fired at only 70 yards from the Turkish ironclad, we must then believe that this ship was herself very close to the reef; the slightest change of position would have put her on shore. It is not probable that her captain should have chosen, in the vast Bay of Batoum, such a perilous position. May we suppose that the Russian torpedo met some submarine defences arranged by the Turks? The latter were, doubtless, competent to attempt such a system of defence, but no accounts credit them with such an effort.

It is necessary to search elsewhere for the explanation of the Russian failure. When they attacked, the night was very dark, consequently they may have considerably misjudged the distance which separated them from the enemy. Every seaman knows that in profound darkness the loom of a large ship suddenly appearing presents a misleading idea of height and length. The Russian officers profess to have followed on the water the track of the "Tchesme's" torpedo on its way to the beam of Turkish ship, but the adjusting of a Whitehead torpedo is a most delicate operation; so that, in their path, these machines do not always follow a straight line. It is, therefore, very possible that the Russians fired their torpedoes at a much greater distance than 70 yards from the Turk, and that they, swerving slightly, passed astern of the vessel, and struck the reefs of the neighboring shore. This supposition appears even more admissible, since from the reports of the Russian officers, the "Sinope's" Whitehead took a direction towards the stern of the ironclad.

Besides, the methods adopted for discharging the torpedoes from the "Tchesme" and from the "Sinope" were probably defective; a movable tube under the boat's bottom, or the expedient of an accompanying raft, do not seem to us to be very convenient arrangements for pointing a Whitehead. Did the Russians improve these arrangements before the third affair at Batoum? We do not know; but the rapidity with which the attacked Turkish ship sank would lead us to suppose that both the Whiteheads fired in this case by the "Tchesme" and "Sinope" reached their destination.

We see that on the Danube the Russians made no attempt with the Whitehead. Rivers, and sea coasts with strong tides, and all estuaries with currents, are essentially unfavorable to the employment of these engines, even

against vessels at anchor. Both the boats and the torpedoes find themselves, then, subject to too many exterior influences for pointing of the torpedo to be performed with accuracy; a rough sea renders also very ticklish, or even impossible, the discharge of a Whitehead, and finally the difference in density between salt water and fresh might possibly be a great obstacle to the employment on rivers of Whiteheads experimented on and regulated in a maritime port.* Thus, deviations arising from an incorrect estimate of distance, defective adjustment of the rudder, inaccurate pointing, and exterior influences affecting its direction or its depth of immersion, such are the gravest inherent difficulties in the use of Whitehead torpedoes from boats.

Based principally on the experience acquired in the Russo-Turkish War, the foregoing discussion permits us to define the circumstances which appear favorable either to the effective use of spar torpedoes or of the Whitehead torpedo; firstly, against ships at anchor, and secondly, when under weigh.

When a vessel is anchored in the middle of a strong stream, it is very difficult to establish a defence round her waterline, or even a good defensive arrangement of nets and spars from her hull. We have just seen that similar circumstances, above all, with a dark night and a rough sea, render also very uncertain the aim of a Whitehead. Spar torpedoes should then be employed in preference, by boats charged to attack: the darkness will also enable these latter to evade more easily than on a bright night the look-out of the patrol boats and of the enemy's sentries.

When, on the other hand, the night is not too dark, when the sea is calm, and the absence of current permits the attacked vessel to defend herself by exterior defences, the employment of Whiteheads presents good chances of success, which are unattainable for the spar torpedoes.

The opportunity of attacking a vessel under weigh by torpedo boats may offer itself as well by day as by night. No engagement argues for or against the employment of Whiteheads under such circumstances; but the affair at Nicopolis shows that a ship of ordinary speed can protect herself effectively against the employment of spar torpedoes by an arrangement of nets and spars. The use of Whiteheads under such circumstances is thus naturally suggested. We must not forget, however, that the speed of the enemy's ship adds a considerable element to the external causes which render the aim from boats very uncertain. Summing up, it would appear wise to introduce into flotillas intended for coast defence some boats armed with spars, and some with Whitehead torpedoes.

In conclusion, we quote a simile, the truth of which has struck us. The spar torpedo is the dagger which a determined man plunges into the body of an enemy who does not protect himself with a coat of mail; the Whitehead torpedo is the bullet which, easy to discharge from afar, kills the enemy in its path, but which very often strays uselessly far from its mark.

Till now, we have only examined the actions fought by the torpedo boats from the point of view of the assailants, let us see if they offer us any useful hints as to the defence. That the "Minnesota," "Wabash," and the "Memphis" were neither sunk nor seriously damaged by the Confederate "Davids" was owing chiefly to the extreme watchfulness of their crews; but the "Houssatonic," which was on her guard, since she had slipped her cable at the moment of the explosion, was, nevertheless, destroyed by Lieutenant Dixon's boat. The Turkish ships moored at Matchin and before Soukhoum Kale had patrol boats out, but yet the "Seife" was sunk, and the "Assar-i-Chefket" only escaped the same fate through the bad management of the weapons brought against her. One sees, therefore, that the most careful watchfulness is not always sufficient guarantee against the attack of torpedo boats. All the actions which we have reviewed show equally, in a most decided manner, the inefficiency in these cases of a defence based solely on artillery and rifle fire. On the other hand, if the "Albemarle" was sunk in spite of the stockade around her, we have seen that simple ropes stretched round the "Idjalick" baulked

* *Note by Translator.*—This objection is slight, as all our Woolwich torpedoes are regulated in fresh water, the difference between their performance in that and in salt water being inappreciable.

the efforts of the Russians, and that the monitor attacked before Nicopolis probably owed her escape to the nets and spars extended from her hull. The objection is raised to the use of such systems of defence, of the necessity of a ship liable to the attacks of torpedo boats being always ready to get under weigh; but the example of the "Houssatonic" proves that this latter precaution is insufficient to save a ship from the attack of a fast torpedo boat. Besides, need the getting under weigh be prohibited by a system of nets and booms arranged round the vessel? Decidedly not, since the Turkish monitor at Nicopolis used this species of defence while actually under weigh. Such a feat cannot have too much importance attached to it, which has demonstrated practically the possibility of defending, externally, the hull of a steamer under weigh; and, hence, the necessity of seriously studying this subject. We are well aware that in the open sea, even at slow speed, the employment of nets and spars would be impossible, but it is nearly always at mouths of rivers, in narrow passages, and in roadsteads, in generally calm water, that ships will have to defend themselves against the attacks of torpedo boats.

In addition, or in default of spars and nets stretched from the hull, a ship at anchor can, under certain circumstances, protect herself effectively by means of "stockades" attached to boats or to buoys moored around her. It was thus that the Turkish stockade at Sulina was made that baffled the efforts of the Russian torpedo boats. The Ottoman ships at Batoum were in excellent positions for following that example. Their bows fast to an anchor ahead, and their sterns moored to the shore, they had every facility for establishing a good stockade some yards from their hulls, which would have been practically immovable. It is evident that in tideways, or variable winds, a ship swinging to her anchors could not adopt similar arrangements, in consequence of the too great room required for her movements.

Hence, the events of the Turco-Russian War seem to indicate the following measures as the most advantageous for the protection of a ship against the attacks of torpedo boats, to be combined according to the different circumstances which present themselves. One watch of the crew to sleep at their quarters all the night; machine guns and guns of small caliber loaded and depressed in advance; steam up and cables ready to slip; a system of nets and booms extended from the ship; a stockade of the description of that employed by the Turks before Sulina; rowing boats protecting this stockade, armed with guns or machine guns; and, finally, at a distance of not less than 100 yards, one or more boats under steam, their object being to give the alarm, and yet more to rush with all speed on an enemy's boats, which might be preparing to use Whitehead torpedoes. A vessel thus prepared may not be invulnerable, but she would have, we believe, much the best chance on her side.

Conclusion.

In summing up, these are the conclusions to which we bring our examination of the engagements passed in review in the first part of this article.

1st. The attacks made by torpedo boats during the American and Turco-Russian Wars were delivered under conditions such that their results ought to be taken into serious consideration, with the view of extracting information. These results appear to establish the following points:

2nd. An attack made against a ship by means of a torpedo boat does not require more exceptional circumstances, nor more absolute devotion, than any other operation of naval war.

3rd. An attack of this description, where the assailant only risks forces relatively small, offers such chances of success that it should always be tried when the occasion presents itself.

4th. One single torpedo boat, of moderately good quality, is sufficient to surprise at night a vessel at anchor; a day attack, on a vessel under weigh, requires the co-operation of several torpedo boats, especially built for the purpose.

5th. Under all circumstances where such boats, collected into a flotilla, have to attack one or more ships, their attacks should be simultaneous.

6th. The use of "diverging torpedoes" in boats should be discontinued.

7th. Spar torpedoes are usefully em-

ployed by boats attacking, on a very dark night or with a slightly agitated sea, a ship moored amongst strong currents, or which may be expected not to be protected by external defences.

8th. Whitehead torpedoes will be employed by preference when the night is comparatively clear, the sea very calm, the current slight, and when one may suppose the enemy's ship to be provided with obstacles.

9th. Against a vessel under weigh, the two species of torpedoes will both respectively find their value, according to cirumstances. It would appear, then, to be best to combine, in a flotilla intended for the defence of harbors and roadsteads, both spar and Whitehead torpedo boats.

10th. Whenever circumstances will permit, a ship at anchor should guarantee herself against the attack of torpedo boats, not only by the help of a good watch on board and abroad, but also by obstacles attached to her, or by an independent stockade, or even by combining the two systems.

11th. Finally, in certain circumstances, a ship under weigh may defend herself advantageously against torpedo boats by booms and nets.

It is necessary to add that we have not the slightest pretension to laying down here what are termed the principles of torpedo warefare. We have simply endeavored to draw some useful information from the conscientious examination of the different sea fights in which torpedo boats have taken part.

The torpedo is an arm too recent not to undergo, before long, transformations which may considerably modify its method of employment. In the meantime, let us profit by the lessons taught us by these seamen, the first who have used these redoubtable weapons of war

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THE GEOMETRICAL INTERPRETATION OF IMAGINARY QUANTITIES.

Translated from the French of M. Argand by Prof. A. S. HARDY.

Contributed to VAN NOSTRAND'S ENGINEERING MAGAZINE.

III.

22. Let us now assume some point other than the center K (Fig. 16), as V, and find the product of VA, VB, VC, ..., VG.

Since $\overline{VA}=\overline{VK}+\overline{KA}$, and $\overline{VB}=\overline{VK}+\overline{KB}$, ... we have

$$\overline{VA}.\overline{VB}.\overline{VC} \ . \ . \ . \ \overline{VG}=$$
$$(\overline{VK}+\overline{KA})(\overline{VK}+\overline{KB}) \ . \ . \ .$$
$$(\overline{VK}+\overline{KG})=\overline{VK}^n+\Pi'.\overline{VK}^{n-1}+$$
$$\Pi''.\overline{VK}^{n-2}+. \ . \ . \ . \Pi^{(n-1)}.\overline{VK}+\Pi^{(n)}.$$

Now we have just seen that the coefficients Π', Π'', Π''', . . . , to $\Pi^{(n-1)}$ are zero, and that $\Pi^{(n)}=-(-1)^n$. Hence

$$\overline{VA}.\overline{VB}.\overline{VC} \ . \ . \ . \ \overline{VG}=\overline{VK}^n-(-1)^n$$
$$=(-\overline{KV})^n-(-1)^n=(\overline{KV}^n-1)(-1)^n.$$

To construct $\overline{KV}^n$, lay off $\overline{AKU}$ equal to n times $\overline{AKV}$. Make $KU = KV^n$, whence $\overline{KU}^n = \overline{KV}^n$. Therefore

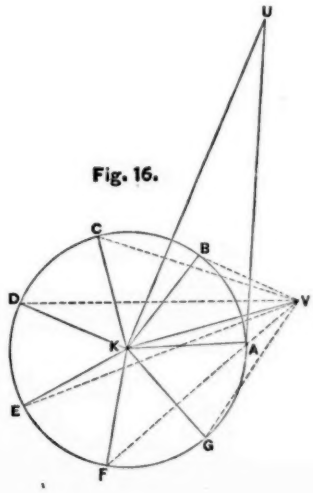


Fig. 16.

$\overline{KV}^n-1=\overline{KU}-1=\overline{KU}-\overline{KA}$
$=\overline{KU}+\overline{AK}=\overline{AU}$,

and $\overline{VA}.\overline{VB}.\overline{VC}\ldots\overline{VG}=(-1)^n\overline{AU}$.

If we consider VA, VB, ... , VG and AU as positive prime lines, we may make $\overline{VA}=r'.VA, \overline{VB}=r''.VB, \ldots, \overline{VG}=r^{(n)}VG$ and $\overline{AU}=\rho.AU$; $\rho, r', r'', \ldots, r^{(n)}$ being directed radii or the roots of unity. We should then have

$r'.r''.r'''\ldots r^{(n)}.VA.VB.VC\ldots VG$
$=(-1)^n\rho.AU$,

and (No. 12, § 8), VA.VB . . . . VG=AU. For example, let KV=x, KU=x^n, the angle AKV=a, the angle AKU=na, the angle AKB=$\frac{2\pi}{n}$. We should then find

$$AU^2=x^{2n}-2x^n\cos na+1,$$
$$VB^2=x^2-2x\cos\left(a-\frac{2\pi}{n}\right)+1,$$
$$VC^2=x^2-2x\cos\left(a-\frac{4\pi}{n}\right)+1,$$
$$VD^2=x^2-2x\cos\left(a-\frac{6\pi}{n}\right)+1,$$
$$\ldots\ldots\ldots\ldots,$$
$$VA^2=x^2-2x\cos\left(a-\frac{2\pi n}{n}\right)+1$$
$$=x^2-2x\cos a+1,$$

and, squaring the equation VA.VB . . . VG=AU, we shall have

$$x^{2n}-2x^n\cos na+1=$$
$$\left\{x^2-2x\cos\left(a-\frac{2\pi}{n}\right)+1\right\}$$
$$\times\left\{x^2-2x\cos\left(a-\frac{4\pi}{n}\right)+1\right\}$$
$$\times\left\{x^2-2x\cos\left(a-\frac{6\pi}{n}\right)+1\right\}$$
$$\times\ldots\ldots\times(x^2-2x\cos a+1),$$

there being n factors in the second member.

The development of the rational factors of the first or second degree of the binomials x^n+1, x^n-1, is obtained by making $\cos na=1$ and $\cos na=0$ in this formula. On this well known fact it is unnecessary to be more specific.

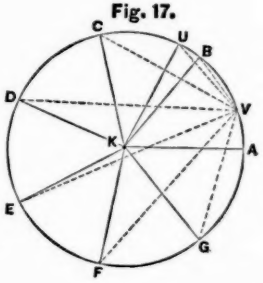
23. If V (Fig. 17) be on the circumference, we have

$$AU=2\sin\frac{na}{2},$$
$$VA=2\sin\frac{a}{2},$$
$$VB=2\sin\left(\frac{\pi}{n}-\frac{a}{2}\right),$$
$$VC=2\sin\left(\frac{2\pi}{n}-\frac{a}{2}\right),$$
$$\ldots\ldots\ldots,$$
$$VG=2\sin\left\{\frac{(n-1)\pi}{n}-\frac{a}{2}\right\}.$$

Hence, substituting a for $\frac{a}{2}$ and

$$\sin\left(\frac{n\pi}{n}-a\right)=\sin(\pi-a)$$

Fig. 17.



for sin a, there results

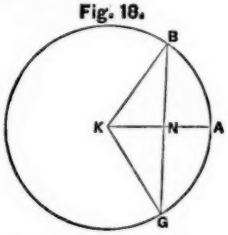
$$2\sin na=$$
$$2^n.\sin\left(\frac{\pi}{n}-a\right)\sin\left(\frac{2\pi}{n}-a\right)\sin\left(\frac{3\pi}{n}-a\right)$$
$$\ldots\times\sin\left\{\frac{(n-1)\pi}{n}-a\right\}\sin\left(\frac{n\pi}{n}-a\right).$$

Making $a=\frac{\pi}{2n}-b$, we obtain $na=\frac{\pi}{2}-nb$ and $\sin na=\cos nb$. The substitution of these values gives

$$2\cos nb=2^n\cos$$
$$\left\{\frac{(n-1)\pi}{2n}-b\right\}\cos\left\{\frac{(n-3)\pi}{2n}-b\right\}$$
$$\times\cos\left\{\frac{(n-5)\pi}{2n}-b\right\}\ldots\times\cos$$
$$\left\{\frac{[n-(2n-3)]\pi}{2n}-b\right\}\times\cos$$
$$\left\{\frac{[n-(2n-1)]\pi}{2n}-b\right\}.$$

24. In Fig. 18, make the arc AB=arc AG; then $\overline{KN}=\overline{KB}+\overline{BN}$ and $\overline{KN}=\overline{KG}+\overline{GN}$; whence we obtain, observing that $\overline{BN}+\overline{GN}=0$, and that $\overline{KG}=\overline{KB}^{-1}$,

Fig. 18.



$$2\overline{KN}=\overline{KB}+\overline{KB}^{-1}.$$

Raising both members of this equation to the nth power, n being a whole number, it becomes

$$(2\overline{KN})^n=\overline{KB}^n+n\overline{KB}^{n-2}+\frac{n(n-1)}{2}.\overline{KB}^{n-4}+\ldots+\frac{n(n-1)}{2}.\overline{KB}^{-n+4}+n\overline{KB}^{-n+2}+\overline{KB}^{-n}.$$

Making the arc $AB=a$, then $\overline{KN}=\cos a$, $\overline{KB}=\cos a\sim\sin a$, and, in general, $\overline{KB}^m=\cos ma\sim\sin ma$. Substituting these values in the above equation, and, since the first member contains no medial terms, suppressing those of the second member, we have

$$(2\cos a)^n=\cos na+n\cos(n-2)a+\frac{n(n-1)}{2}\cos(n-4)a+\ldots+\frac{n(n-1)}{2}\cos(-n+4)a+n\cos(-n+2)a+\cos(-na).$$

Since, in general, $\cos m=\cos(-m)$, the terms of the second member may be added two and two; but two cases must be distinguished, according as n is even or odd. In the first case, the number of the terms in the second member is odd and the middle term stands alone; this term is

$$\frac{n(n-1)(n-2)\ldots\left\{n-\left(\frac{n}{2}-1\right)\right\}}{1.\,2.\,3\ldots\frac{n}{2}}$$

$$\cos(n-n)a=\frac{n(n-1)\ldots\left(\frac{n}{2}+1\right)}{1.\,2.\,3\ldots\frac{n}{2}}.$$

In the second case, all the terms are doubled, and, if we begin the series with $\cos na+\cos(-na)=2\cos na$, the last term will be

$$2\frac{n(n-1)(n-2)\ldots\left\{n-\left(\frac{n-1}{2}-1\right)\right\}}{1.\,2.\,3\ldots\frac{n-1}{2}}\cos[n-(n-1)]a=.$$

$$2\frac{n(n-1)(n-2)\ldots\frac{n+3}{2}}{1.\,2.\,3\ldots\frac{n-1}{2}}\cos a.$$

In the same way may be found the value of $(2\sin a)^n$. We have $\overline{NB}=\overline{NK}+\overline{KB}$, $\overline{NG}=\overline{NK}+\overline{KG}$; but $\overline{NG}=-\overline{NB}$ and $\overline{KG}=\overline{KB}^{-1}$; whence $2\overline{NB}=\overline{KB}-\overline{KB}^{-1}$, and

$$(2\overline{NB})^n=\overline{KB}^n-n.\overline{KB}^{n-2}+\frac{n(n-1)}{2}.\overline{KB}^{n-4}-\ldots\pm\frac{n(n-1)}{2}.\overline{KB}^{-n+4}\mp n.\overline{KB}^{-n+2}\pm\overline{KB}^{-n}=(\sim 2\sin a)^n.$$

The upper and lower signs correspond respectively to the cases in which n is even or odd. Examine first the former. $(\sim 2\sin a)^n$ is then of the prime order, and the medial terms in the development of the second member may be neglected; whence

$$\pm(2\sin a)^n=\cos na-n\cos(n-2)a+\frac{n(n-1)}{2}\cos(n-4)a-\ldots+\frac{n(n-1)}{2}n\cos(-n+4)a-n\cos(-n+2)a+\cos(-na).$$

In the first member we take the plus sign when n is of the form $4m$, and the minus sign when n is of the form $4m+2$. The middle term, which is

$$\frac{n(n-1\ldots\left(\frac{n}{2}+1\right)}{1.\,2.\,3\ldots\frac{n}{2}},$$

as in the formula for the cosine, is not doubled.

In the second case, $(\sim 2\sin a)^n$ is of a medial order. Hence the prime terms of the second member must be dropped, which gives, after dividing the equations by ~ 1,

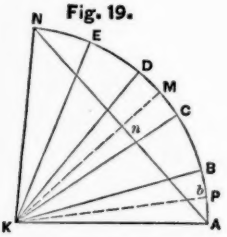
$$\pm(2\sin a)^n = \sin na - n\sin(n-2)a + \frac{n(n-1)}{2}\sin(n-4)a - \ldots \frac{n(n-1)}{2}\sin(-n+4)a + n\sin(-n+2)a - \sin(-na).$$

The + and − signs correspond respectively to the cases in which n is of the form $4m+1$ and $4m+3$. Here all the terms are equal two and two; for, in general, $\sin m = -\sin(-m)$, and the number of terms is even. Uniting, therefore, as above, the equal terms, the series reduces to $\frac{n+1}{2}$ terms, the last of which is

$$\frac{n(n-1)\,(n-2)\ldots\frac{n+3}{2}}{1.\,2.\,3\ldots\frac{n-1}{2}}\sin a.$$

25. Suppose the arc AN divided into n equal parts AB, BC, ... , EN (Fig. 19).

Fig. 19.



Draw AN and AB and through their middle points, n and b, the radii KM, KP. Then

$$\overline{KB}+\overline{KC}+\overline{KD}+\ldots+\overline{KN} = \cos a \sim \sin a + \cos 2a \sim \sin 2a + \cos 3a \sim \sin 3a + \ldots + \cos na \sim \sin na = C \sim S,$$

where

$$C = \cos a + \cos 2a + \cos 3a + \ldots + \cos na,$$
$$S = \sin a + \sin 2a + \sin 3a + \ldots + \sin na.$$

Let $\overline{KB} = u$, $\overline{KC} = u^2$, ... , $\overline{KN} = u^n$; whence

$$\overline{KB}+\overline{KC}+\ldots+\overline{KN} = u+u^2+u^3+\ldots+u^n = \frac{u^n-1}{u-1}\cdot u = \frac{\overline{KN}-\overline{KA}}{\overline{KB}-\overline{KA}}\cdot u = \frac{\overline{KN}+\overline{AK}}{\overline{KB}+\overline{AK}}\cdot u = \frac{\overline{AN}}{\overline{AB}}\cdot u = \frac{n\overline{N}}{b\overline{B}}\cdot u.$$

But (No. 12, § 4)

$$n\overline{N} = \sim\sin\frac{na}{2}\times\overline{KM} = \sim\sin\frac{na}{2}\cdot u^{\frac{n}{2}},$$

$$b\overline{B} = \sim\sin\frac{a}{2}\times\overline{KP} = \sim\sin\frac{a}{2}\cdot u^{\frac{1}{2}}.$$

Hence

$$C\sim S = \frac{\sim\sin\frac{na}{2}\cdot u^{\frac{n}{2}}}{\sim\sin\frac{a}{2}\cdot u^{\frac{1}{2}}}\cdot u = \frac{\sin\frac{na}{2}}{\sin\frac{a}{2}}\cdot u^{\frac{n+1}{2}} = \frac{\sin\frac{na}{2}}{\sin\frac{a}{2}}\left(\cos\frac{n+1}{2}a \sim \sin\frac{n+1}{2}a\right).$$

Equating the terms of like order, we have

$$C = \frac{\sin\frac{na}{2}\cdot\cos\frac{n+1}{2}a}{\sin\frac{a}{2}}$$

and

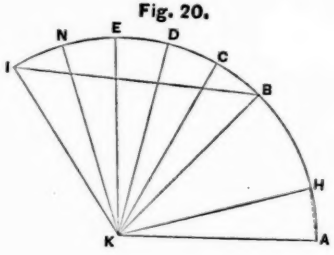
$$S = \frac{\sin\frac{na}{2}\cdot\sin\frac{n+1}{2}a}{\sin\frac{a}{2}}.$$

26. A similar process will lead to the reduction of

$$K = \cos a + \cos(a+b) + \cos(a+2b) + \ldots + \cos(a+nb),$$
$$\Sigma = \sin a + \sin(a+b) + \sin(a+2b) + \ldots + \sin(a+nb).$$

To this end, describe the arcs AB = a, BC, CD, . . . , EN = b (Fig. 20), the latter

Fig. 20.



being n in number. Make, moreover, AH = NI = b, and draw BI and AH. Then if $\overline{KH} = u$, $\overline{KB} = v$, we have

$$\overline{KC} = vu,\ \overline{KD} = vu^2,\ \ldots,\ \overline{KN} = vu^n,\ \ \overline{KI} = vu^{n+1}.$$

Therefore

$$K\sim\Sigma=v+vu+vu^2+\ldots+vu^n=\frac{vu^{n+1}-v}{u-1}=\frac{\overline{KI}-\overline{KB}}{\overline{KH}-\overline{KA}}=\frac{\overline{KI}+\overline{BK}}{\overline{KH}+\overline{AK}}$$

$$=\frac{\overline{BI}}{\overline{AH}}=\frac{\frac{1}{2}\overline{BI}}{\frac{1}{2}\overline{AH}}=[\text{No. 12, § 6}]$$

$$\frac{\sim\sin\left(\frac{n+1}{2}b\right).\overline{K.(AB+\frac{1}{2}BI)}}{\sim\sin\frac{1}{2}b.\overline{K.\frac{1}{2}AH}}=$$

$$\frac{\sim\sin\left(\frac{n+1}{2}b\right).\overline{K.(AB+\frac{1}{2}BN)}}{\sim\sin\frac{1}{2}b}=$$

$$\frac{\sin\left(\frac{n+1}{2}b\right)}{\sin\frac{1}{2}b}\left\{\cos\left(a+\frac{bn}{2}\right)\sim\sin\left(a+\frac{bn}{2}\right)\right\},$$

or, equating terms of like order,

$$K=\frac{\sin\left(\frac{n+1}{2}b\right)\cos\left(a+\frac{bn}{2}\right)}{\sin\frac{1}{2}b}$$

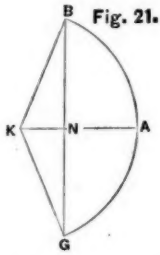
and

$$\Sigma=\frac{\sin\left(\frac{n+1}{2}b\right)\sin\left(a+\frac{bn}{2}\right)}{\sin\frac{1}{2}b}.$$

27. What precedes is sufficient to show that the method here presented may be employed in trigonometrical researches. It may also be of some use in elementary geometry and algebra, as will now be briefly indicated.

28. Let Fig. 21 be constructed; its

Fig. 21.

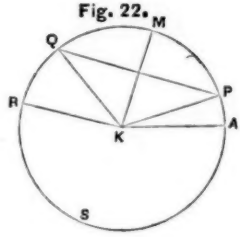


simplicity and analogy, with those already made use of, renders its explanation unnecessary. It follows from the rules of multiplication and addition that $\overline{KB}\times\overline{KG}=\overline{KA}^2$, and $\overline{KB}=\overline{KN}+\overline{NB}$, $\overline{KG}=\overline{KN}+\overline{NG}$. Hence $\overline{KA}^2=(\overline{KN}+\overline{NB})(\overline{KN}+\overline{NG})$. Let $KA=h$, $KN=a$, $NB=NG=b$. Then

$$h^2=(a\sim b)(a+b)=a^2+b^2.$$

29. Any directed chord $\overline{PQ}$ (Fig. 22) is of the same order and sign as the radius $\overline{KR}$, drawn in the direction of this

Fig. 22.



chord. Now the angle AKR is equal to $\frac{AP+AQ+\pi}{2}$; for, drawing KM perpendicular to PQ, we have

$$\text{arc AR}=AP+PM+MR=AP+\tfrac{1}{2}PQ+\frac{\pi}{2}=AP+\tfrac{1}{2}(AQ-AP)+\frac{\pi}{2}=\frac{AP+AQ+\pi}{2}.$$

The radius $\overline{KR}$ may therefore be expressed (No. 12, § 6) by $K.\left(\frac{AP+AQ+\pi}{2}\right)$, an expression indicating the direction of the chord $\overline{PQ}$. On this expression we also remark that the chord $\overline{PQ}$ being indeterminate, the letters P and Q may be interchanged, and for $\overline{QP}$ we should have

$$\overline{K.\left(\frac{AQ+AP+\pi}{2}\right)},$$

an expression identical with the former; for $AP+AQ=AQ+AP$. We should infer from this that $\overline{PQ}$ and $\overline{QP}$ have the same direction, which is, however, not the case, since they are reciprocally positive and negative. To solve this difficulty we observe that the designation of an arc by its two terminal points, as AP, applies to an infinite number of arcs, as $AP+2n\pi$, n being any integer. In such expressions, then, as the above, of all these arcs that one should be taken which conforms to the construction followed in the establishment of the general formula. Suppose the point Q to move in the direction QRS until it reaches P, and that, at the same time, P moving in the same direction, reaches Q. The chord PQ will then be what was

before the chord $\overline{QP}$. The direction of this chord $\overline{PQ}$ will still be

$$\overline{K.\left(\frac{AP+AQ+\pi}{2}\right)};$$

but, in this last expression, the arc AP should be estimated from A, round the entire circumference, plus the arc AP itself, so that this expression really differs from the former by the quantity $\frac{2\pi}{2}=\pi$, as it should.

To avoid all ambiguity, it is sufficient in the general formula

chord $\overline{PQ}$ *having the direction*

$$\overline{K.\left(\frac{AP+AQ+\pi}{2}\right)},$$

to consider the arc AQ greater than the arc AP, following along the circumference in either direction from A to P to determine the arc AP, and then continuing in the same direction till Q is reached. Thus for $\overline{K.\left(\frac{AP+AQ+\pi}{2}\right)}$ we might write $\overline{K.\left(\frac{2AP+PQ+\pi}{2}\right)}$, the arcs AP and PQ being estimated in the same direction. In addition to the foregoing it may be remarked that, if the chord $\overline{PQ}$ is divided at N into any two segments, the part $\overline{NQ}$ has the same direction as $\overline{K.\left(\frac{AP+AQ+\pi}{2}\right)}$, and the part $\overline{NP}$, which relative to $\overline{NQ}$ is negative, has the direction

$$\overline{K.\left(\frac{AP+AQ+\pi}{2}-\pi\right)}=\overline{K.\left(\frac{AP+AQ-\pi}{2}\right)}.$$

Hence, remembering that in general the product of two lines having the directions $\overline{K.FG}$, $\overline{K.HI}$ is in the direction of $\overline{K.(FG+HI)}$, we conclude that the product $\overline{NP}.\overline{NQ}$ will have the direction $\overline{K.(AP+AQ)}$.

30. Take now any four points P,Q,R,S; remembering that in general $\overline{MN}=-\overline{NM}$, we may write

$$\overline{PS}.\overline{QR}+\overline{RS}.\overline{PQ}=\overline{PS}.\overline{QR}+(\overline{RQ}+\overline{QS})(\overline{PS}+\overline{SQ})=\overline{PS}.\overline{QR}+\overline{RQ}.\overline{PS}+\overline{RQ}.\overline{SQ}+\overline{QS}.\overline{PS}+\overline{QS}.\overline{SQ}=\overline{RQ}.\overline{SQ}+\overline{QS}.\overline{PS}+\overline{QS}.\overline{SQ}=\overline{QS}(\overline{QR}+\overline{PS}+\overline{SQ})=\overline{QS}.\overline{PR}.$$

Now, if the points P, Q, R, S are so situated that the three products of the final equation $\overline{PS}.\overline{QR}+\overline{RS}.\overline{PQ}=\overline{QS}.\overline{PR}$ have the same direction, this equation will be true of absolute lines. This condition will be satisfied if the points in question are taken in the order P, Q, R, S, on the circumference, in which case PQ, QR, RS, PS are the sides of a quadrilateral whose diagonals are PR, QS. In fact, these sides and diagonals being so many chords of the circle, we may, by the formula of the preceding article, form the following table, the origin of the arcs A being supposed to immediately precede the point P:

Chords.	Directions.
$\overline{PS}$	$\overline{K.\left(\frac{AP+AS+\pi}{2}\right)}$
$\overline{QR}$	$\overline{K.\left(\frac{AQ+AR+\pi}{2}\right)}$
$\overline{RS}$	$\overline{K.\left(\frac{AR+AS+\pi}{2}\right)}$
$\overline{PQ}$	$\overline{K.\left(\frac{AP+AQ+\pi}{2}\right)}$
$\overline{QS}$	$\overline{K.\left(\frac{AQ+AS+\pi}{2}\right)}$
$\overline{PR}$	$\overline{K.\left(\frac{AP+AR+\pi}{2}\right)}$

and these expressions will be free from ambiguity, because, on account of the supposed order in which A,P,Q,R and S are taken, these six chords are all taken in the same direction.

Hence, in virtue of the principle cited above, the three products $\overline{PS}.\overline{QR}$, $\overline{RS}.\overline{PQ}$, $\overline{QS}.\overline{PR}$ have the same direction, namely, that of

$$\overline{K.\left(\frac{AP+AQ+AR+AS+2\pi}{2}\right)}.$$

Thus, then, for absolute lines, we have $\overline{PS}.\overline{QR}=\overline{RS}.\overline{PQ}+\overline{QS}.\overline{PR}$. This demonstration, far more simple than the ordinary one founded only on the comparison of similar triangles, is here given only as illustrative of the use of intermedials, of which little has been said.

31. In this last article we propose to show that every polynomial of the form $X^n+aX^{n-1}+bX^{n-2}+\ldots+fX+g$ is decomposable into factors $X+\alpha$ of the first degree. It is to be noticed that $a, b, \ldots g$ are not necessarily reals, as is ordinarily the case.

It is well known that the problem consists in the proof that a quantity can always be found which, substituted for X, will render the polynomial zero, which latter we make $=Y$. Denote by $Y_{(p)}$, $Y_{(p+\rho i)}$ the values of Y obtained by making $X=p$, $X=p+\rho i$, p and i being arbitrary numbers and ρ a directed radius or an indeterminate root of unity. We then have $Y_{(p)}=p^n+ap^{n-1}+bp^{n-2}+\ldots+g$, $Y_{(p+\rho i)}=(p+\rho i)^n+a(p+\rho i)^{n-1}+b(p+\rho i)^{n-2}+\ldots+g=Y_{(p)}+i\rho Q+i^2\rho^2R+i^3\rho^3S+\ldots$, Q, R, S being known quantities, dependent on p, n, a, b, c, . . . , and obtained from the development of the powers of $p+\rho i$. If i be supposed infinitely small, the terms containing i^2, i^3, . . . , disappear, and we have simply $Y_{(p+\rho i)}=Y_{(p)}+i\rho Q$. Let $\overline{KP}$ have the direction of $Y_{(p)}$. Assume ρ so that $i\rho Q$ shall have the direction $\overline{PK}$, that is of the same order as $Y_{(p)}$, but opposite in direction; it follows that the magnitude of $Y_{(p+\rho i)}$ will be less than that of $Y_{(p)}$; similarly we may obtain a new value of Y which shall be less than that of $Y_{(p+\rho i)}$, and so on, and finally therefore a value of X for which $Y=o$.

To render the demonstration complete, it must be remarked that the term $i\rho Q$ may become zero. In this case we should retain the succeeding term $i^2\rho^2R$, or, should this disappear, $i^3\rho^3S$, and so on. The reasoning remains the same, because the powers ρ^2, ρ^3, . . . are quantities of the same nature as ρ.

32. The method above explained rests upon two principles of construction, one for the multiplication, the other for the addition of directed lines; and it has been already observed that inasmuch as these principles depend upon inductions which are not securely established, they cannot, as yet, be considered as other than hypotheses, whose acceptance or rejection should depend upon either the consequences which they entail or a more rigorous logic.

We might have dwelt more fully upon the fundamental ideas which lead to these results. We might have indicated, by some comparisons, how certain points, in the theories of Algebra and Geometry, bear upon these principles admitted by induction, whose truth is established rather by the exactness of their consequences than by the logic on which they are founded; but this discussion would have contributed nothing essential to the foregoing, and we confine ourselves to proposing the method of directed lines as an instrument of research, whose use is advantageous in certain cases, because geometric constructions offer, as it were, a picture to the eye which facilitates purely intellectual operations. Moreover, it is always possible to translate the demonstrations founded on this method into ordinary language.

THE ANNUAL RAINFALL IN ITS RELATION TO THE WATER SUPPLY OF A CITY.

By P. H. BAERMANN, C. E.

Abstract of a Paper read before the Pi Eta Society, Troy, N. Y.

If a vessel is filled with water and exposed to the air, the quantity becomes diminished and after a time entirely disappears. Non-absorbent objects, wet by showers, become dry soon after the sun begins to shine upon them, the water in both cases being evaporated, converted by heat into vapor and diffused through the air.

So evaporation goes on from the entire land and water surface of the earth.

The air is only capable of receiving a certain amount of vapor; this capacity depends principally upon the temperature, increasing with heat and decreasing with cold.

When the limit of absorption is reached the air is said to be at its point of

saturation, and any further supply floats in the form of clouds or mist, or is returned to its liquid condition and falls to the earth.

As the quantity of vapor in the atmosphere increases, or a fall in the temperature causes its more rapid condensation, the clouds receiving this condensation become heavier and sink to a lower level, the small globules of water of which they are composed become larger, form drops of rain which, increasing in size, fall to the earth. Thus, the supply of all fresh water sources, be it wells, springs, brooks, rivers or lakes, is furnished by the condensation of the vapor in the air, precipitated in the form of rain, dew or snow. As the fresh water upon the earth is so small in area compared with the ocean, we regard the sea as the source of all water supplies.

It will be interesting to consider briefly the causes producing the annual precipitation, the distribution of which varies so greatly in different places and at different seasons, yet locally so regular in its coming and amount that it must be the result of laws as sure in their operation as the seasons in their rounds.

"The sea supplies the winds with food for the rain which these busy messengers convey from the ocean to 'the springs in the valleys which run among the hills.' To the philosopher, the places which supply the vapors are as suggestive and as interesting for the instruction they afford, as the places are upon which the vapors are showered down. Therefore, as he who studies the physical geography of the land is expected to make himself acquainted with the regions of precipitation, so he * * * should search for the regions of evaporation, and for the springs in the ocean which supply the reservoirs among the mountains with water to feed the rivers; and in order to conduct this search properly, he must consult the winds and make himself acquainted with their circuits."

For about thirty degrees upon each side of the equator, and separated by a region of equatorial calms, we have two zones of constant winds extending entirely around the earth; those upon the north called the N. E. trade winds, those upon the south S. E. trade winds, blowing continually and almost invariably in the same direction.

The belt of calms, having a width of about 6 degrees, travels during the year with the sun, back and forth over about 17 degrees of latitude, coming north in the summer and returning, reaches its extreme southern latitude in March or April, thus having a width of from 5 to 7 degrees and a motion north and south of 17 degrees. It is evident that some localities are covered twice annually by this zone, and as within this zone it rains almost constantly there are places which have two rainy seasons.

This zone of calms is formed by the meeting of the two trade winds.

"* Warmed by the heat of the sun, and pressed on each side by the whole force of the N. E. and S. E. trades, these two winds cease to move onward, and ascend.

"This operation is the reverse of what takes place near the 30th parallel. Having ascended to the upper regions of the atmosphere again, the wind travels counter to the N. E. and S. E. trades until it meets, near the 30th degree, the winds from the north and south poles coming to take its place." Another belt of calms occurs here "from under which two surface currents of wind are ejected, those towards the equator being the trades, and those towards the poles the N. and S. W. passage winds." * *

"Hence, we say, that the *primum mobile* of the air is derived from change of specific gravity induced by the freezing temperature of the Polar regions, as well as from change of specific gravity due to the expanding force of the sun's rays within the tropics."

When the trade winds meet and produce the Equatorial calm, the air is heavily charged with moisture absorbed in its passage over large areas of the ocean, and as it cannot escape, except upward, a portion of the vapor is condensed and in this region of calms we have almost constant precipitation.

The balance of the vapor is carried in the upper current until it reaches the 30th parallel, where it becomes a surface wind towards the poles. The decrease in temperature causes condensation, precipitation commences, and, at last reaching the extreme north and south, the whole of the moisture has been extract-

* Maury, "Physical Geography of the Sea."

ed by the low temperature, and as dry air it commences its return to the equator.

In the passage of these winds towards the tropics, they absorb this water after passing the 30th parallel, being until that time upper currents. Those coming from below the equator pass over an evaporating surface of 75,000,000 square miles, while those from above the equator over only 25,000,000.* We should expect, therefore, that the amount of water carried to the northern hemisphere would be one-third greater than that carried to the southern. The deductions from these physical laws are:

1. That the rainfall decreases from the equator towards the poles.

2. That the rainfall is greater in the northern than in the southern hemisphere.

3. That in the temperate zone more rain falls upon the western coast than upon the eastern, while in the tropics the reverse obtains.

4. That the sides of mountains exposed to the prevailing winds are the wet sides.

5. That the regions of greatest precipitation will be on the slopes of mountains first receiving the trade winds, after having crossed the largest water area.

Let us now compare the above deductions with facts and thereby prove or disprove these laws.

TABLE OF MEAN AND MAXIMUM RAINFALL.

Location.	Lat. and Long.		Years of Record.	Mean Annual Rainfall.	Maximum Annual Rainfall.	Authority.
	N. & S.	E. & W.				
Cayenne.....	4°58′N.	52°12′W	6	138		Be'rdmore
Sierra Leone.	9°±N.	3°± W			313	Pet'rmann
Maranham...	3°±N.	44°± W			280	Johnston
Mahabalesh'n 130 Miles inland from Bombay....	18°53′N	72°31′W	14	254	304	Be'rdmore

The quantity of rain falling in a single day in tropical regions is often immense —thus in Sierra Leone, 26 inches fell in two days—and at Cayenne, Admiral Roussin collected 10 inches in ten hours,

*Maury.

while the average annual rainfall of the tropics is placed by Johnston, at 113 inches in the western, and 80 inches in the eastern hemispheres.

The precipitation in the temperate zone is given at 40 inches in the western, and 34 in the eastern hemispheres. The first deduction is therefore proven.

The rainfall is greater in the northern than in the southern hemisphere, the rain gauge showing a difference of 4 inches. While the greater number and size of the rivers in the former than in the latter discharge the increased quantity. Above the 31st degree of latitude we find the N. W. and S. W. winds prevailing, hence the west coasts of the temperate zone first receive and condense the moisture, while from the 29th degree towards the equator we have the trade winds blowing N. E. and S. E., which give to the eastern shores of the torrid zone the greater rainfall.

Thus—the rainfall on the west coast of England is 45 inches; on the east 27.4.

The eastern sides of the Andes receive the trade winds, and in their passage over them the entire moisture is extracted, owing to the low temperature; then these winds pass over the western slope to the Pacific, incapable of furnishing rain. Thus the coast of Peru is rainless.

*From the 30th degree north in the Pacific, where the N. E. trades first strike the ocean, to the region of equatorial calms, they travel over the sea absorbing the vapors due to a tropical sun. Here, laden as they are, they rise and taking a southeast course, pass as upper current until between the 30th and 40th degree, when they become the prevailing winds of the southern hemisphere, and are first intercepted by the Andes of Patagonia, whose temperature of below 32 degrees deprives them of their moisture. 151 inches of rain in 41 days have been recorded, and Mr. Darwin reports that the sea water along this part of the coast is sometimes quite fresh from the vast quantity of rain that falls.

Thus the great truths of Nature become manifest, and by their study and the arrangement of facts do we deduce the laws which control their actions.

*Maury.

Thus we learn "that the rain we see descending, was thawed for us out of the icebergs which have watched the polar star for ages, and the lotus lilies have soaked up from the hill, and exhaled as vapor, snows that rested on the summits of the Alps."

Since "the waters under the Heavens were gathered together and the dry land appeared," the annual round of winter and summer, of rain and sunshine, of seed time and harvest have been constant, owing to the laws which govern the atmosphere and the laws which govern the ocean. In what follows, only the United States, occupying the central portion of the northern division of the American Continent, whose shores washed by the Atlantic ocean on the east, the Pacific on the west, the Gulf of Mexico an the south, and the chain of lakes in the north, its breadth from east to west opproximately 2700 miles, and its length from north to south 1600 miles, with an approximate area of 3,000,000 square miles, will be regarded.

This area may be divided, with reference to the precipitation, into three great regions, namely: That of periodical, frequent and of scanty rainfall.

The first comprises the western portion of the Pacific slope; and here we find a marked example of the effect of the winds. As before stated, the belt of equatorial calms has a motion north and south during the year, of about 17 degrees of latitude, and consequently the trade and passage winds which blow in opposite directions cover alternately the same locality, as they are crowded out of their normal positions. This change of wind does not take place above the 40th parallel, and consequently that portion of the Pacific slope above, receives constantly the rain winds; while below the same parallel the coast receives them in spring and winter, and in summer and fall the trade winds.

Place.	Lat.	Amount of Rain.					
		Spring.	Sum'er.	Autumn.	Winter.	Year.	
San Diego.....	32°42′	2.74	0.75	1.24	5.90	10.63	
San Francisco.....	37°48′	8.81	0.03	3.37	11.38	23.59	18.48 Mean
Sacramento.....	38°33′	9.02	0.00	3.74	8.56	21.32	
Fort Oxford.....	42°44′	19.12	3.00	19.60	26.80	68.52	
Fort Vancouver.....	45°40′	9.28	6.23	10.30	19.69	45.50	55.29 Mean
Fort Steilacoom.....	47°10′	11.19	3.85	15.20	21.51	51.75	

The region of frequent rains extends from the Atlantic westward to the 100th meridian. On that portion—along the Atlantic slope as far as Washington, nearly the same annual quantity falls, and is distributed with remarkable uniformity during the year. South of Washington and in the Gulf States, the greater portion of the rainfall occurs in summer.

Place.	Rain in inches.				
	Spring.	Summer	Autumn	Winter.	Year.
Eastport, Me. ..	8.88	10.05	9.85	10.61	39.39
Charleston, S. C.	9.89	17.45	10.06	7.52	44.92
Baton Rouge....	15.08	19.14	12.48	15.40	62.10

The region of scanty rains, from what precedes, would naturally be sought west of the 100th meridian and east of the Cascade and Sierra Nevada Mountains, including the inland basin of Utah, the eastern slopes of the Rocky Mountains, and the lower portions of the Pacific slope.

Among the mountains frequent showers occur, and in exceptional cases the valleys between are well watered; Santa Fe, with an elevation of 6800 feet, and Fort Massachusetts with an elevation of 8300 feet above tide, both situated in the valley of the Rio Grande, have a mean annual rainfall of between 19 and 20 inches.

The annual rainfall of the desert region through which the great Colorado flows, is estimated at 3 inches; that of the Nilan basin of Utah at 5 inches, the larger portion of which is received in winter.

The greatest amount of rain reported*

* Army Meteorological Register.

for any given year, was in 1846, at Baton Rouge, 116.6 inches, and the least in 1853, at Fort Yuma in lower California, 1.78 inches.

By analyzing the rainfall statistics of the United States, extending over a series of years,* we ascertain that territorial divisions having the same meteorological characteristics yield similar results, both as to the order of the monthly precipitation, and as to the total annual amount.

Fanning, in his able work on water supply, groups the statistics in the following order :

	Mean Annual Rainfall.
Group 1. Atlantic sea coast from Portland to Washington	43.44
" 2. Atlantic sea coast, Virginia to Florida	47.63
" 3. Hudson River Valley, Northern and Western New York, Vermont	34.99
" 4. Upper Mississippi, part of Iowa, Minnesota and Wisconsin	33.27
" 5. Ohio River Valley, western Pennsylvania to eastern Missouri	40.88
" 6. Indian Territory and western Arkansas	38.25
" 7. Lower Mississippi and Red Rivers	51.48
" 8. Mississippi Delta, Coast of Mississippi and Alabama	59.12
" 9. Pacific Coast, San Francisco to Alaska	41.49

Taking the mean fall for each month in the year, and plotting it with reference to a horizontal line as unity, representing the mean monthly fall at one-tewlfth of the mean annual, we obtain a type curve for each group representing the fluctuations of the rainfall for each month :

Curve 1.	Group 1.	Average fluctuation of the year.	Maximum rainfall.	Minimum rainfall.
			Month of	
		Pr. cent.		
1	1	40	August.	January or February
2	2	128	1st August.	April and October.
3	3	66	1st July.	1st February.
4	4	109	30th June.	1st February.
5	5	73	1st June.	January.
6	6	91	May.	January.
8	8	75	August.	October.
	9	232	December.	July.

Making application now to the 3d group, representing the Hudson Valley, Vermont, Northern and Western New York, we can test the type curve with reference to this particular locality where the record of the rainfall has been kept since 1826.

We find the fluctuation of the monthly fall during the last fifty years to be 66 per cent., that the rainfall is a maximum in the month of July, and a minimum in February.

If we take the rainfall for each year since 1826, and construct a curve, we represent the wet and dry periods as they vibrate back and forth about the mean of the whole. From such a figure the following facts are noticeable : The years of low rainfall occur more frequently in twos or threes, 1834–5, 1851–2, 1858–59–60, 1864–65–66. These series of low years appear to succeed each other at regular intervals of from ten to eleven years, thus : 1834–5, 1844, 1854, 1864 and 1875 ; that several years of more than mean rainfall are followed by several of less than the average, thus : 1861–62–63 are followed by 1864–65–66 ; that the average rainfall of a series of low years is about eight-tenths of the mean.

Great storms or unusual draughts affect temporarily the annual results, while a series of years will approach closely to the mean.

In the great storm of October, 1869, there fell during forty hours, between 8 and 9 inches, which caused an average annual rainfall to become a maximum. The record at Troy shows in that month a fall of 13.80 inches, as compared with a mean precipitation for that month of 3.57 inches, so at the present writing, the rainfall during the last 60 days has been very slight, and probably this year will be an unusual minimum. As the drainage area with which the engineer has to deal is comparatively limited, the question of storage becomes of great importance.

When we consider, as deduced above, that the period of low rainfall may extend through a term of three or four years, during which time the annual fall will only equal eight-tenths of the mean, it becomes necessary to determine not only the proportion per annum, but the proportion per month which may be made available. The surface and degree of cultivation affect largely the propor-

* Smithsonian Contributions to Science, Vol. XVIII.

tion of water flowing from any drainage arae, and when possible this should be determined by measuring the amount flowing off and comparing it with the recorded rainfall on the known area. Experiments of this kind are not numerous, but from the record of the drainage of large river and small hill districts in England,* the flow from the Croton and Cochituate basins,† the measurements of the Madison and Eaton Brooks,‡ the following percentages of drainage may be taken as approximately correct:

From mountain slopes or improved rock hills	80 to 90
" woody swampy lands	60 " 80
" undulating pasture and wood-land	50 " 70
" flat cultivated land and prairie	45 " 60

When the area is ample it will be safe in the calculations to take 50 per cent. of the mean annual rainfall as collectable.

Having decided upon the percentage of the annual rainfall which can be collected from the different surfaces, our next step is to ascertain its distribution throughout the year. The average monthly rainfall at Troy, for the last fifty years, divided by one-twelfth of the mean annual fall, will give the ratio of each month, as follows:

Jan.	Feb.	March.	April.	May.	June.
.79	.69	.80	.93	1.06	1.29
July.	Aug.	Sept.	Oct.	Nov.	Dec.
1.35	1.13	1.02	1.19	.96	.82

These ratios may be used in determining approximately the rainfall in any month where the mean annual is known, but they do not represent the amount flowing from a given area. It will be found that when these ratios are the greatest the least amount is collectable, which becomes evident upon consideration, that in July and August the temperature is high, the evaporation greatest, and the percolation into the ground, and the absorption of vegetable life the greatest.

"The analysis of the records of the flow of the average Atlantic coast streams leads to the following approximate estimate of the ratio of the monthly mean rainfall that flows down the streams in each month of the year, in which due consideration of the evaporation from soils and foliage in very dry seasons has not been neglected."*

MONTHLY RATIOS OF FLOW OF STREAMS.

	Ratio of flow.
January	1.65
February	1.50
March	1.65
April	1.45
May	.85
June	.75
July	.35
August	.25
September	.30
October	.45
November	1.20
December	1.60

Here unity equals the mean monthly flow, or one-twelfth the mean annual flow.

We are now able to estimate the quantity which can be collected from a given area not exceeding 100 square miles in extent. Having used as an illustration thus far this city, we will apply the computation to the same locality.

The mean annual rainfall here is 36.15 inches, while as shown in Fig. 6, the series of low year precipitation amounts to about .8 of the mean.

The mean annual flow of the streams from the drainage area, is assumed to be 50 per cent. of the annual rainfall.

$$\frac{36.15 \times 0.5 + 0.8}{12} = 1.205 \text{ inches.}$$

average available rain monthly.

This average, multiplied by the ratios above, gives the depth in inches of available rain flowing in each month, thus:

	Mean monthly Rainfall.		Ratios.		Depth in inches of available Rain flowing Per month.
January	1.205	×	1.65	=	1.98
February	"	×	1.50	=	1.80
March	"	×	1.65	=	1.98
April	"	×	1.45	=	1.74
May	"	×	.85	=	1.02
June	"	×	.75	=	.90
July	"	×	.35	=	.42
August	"	×	.25	=	.30
September	"	×	.30	=	.36
October	"	×	.45	=	.54
November	"	×	1.20	=	1.44
December	"	×	1.60	=	1.92

which quantities have only to be multiplied by the number of acres or square miles in the water shed to determine the amount obtainable.

The fluctuations in the rainfall and in

* Beardmore. † Fanning. ‡ Canal Rep., 1863, 1875.

* Fanning Water Supply.

the flow of streams as above shown, together with the great variation in the consumption, necessitates, in almost every case, large artificial storage. The present article has exceeded greatly the limits originally intended, and therefore, the question of consumption will not be investigated at this time, but before concluding it will be necessary to consider briefly the question of evaporation and percolation, losses which affect largely the available supply.*

Experiments in this country on the annual evaporation from water surfaces are very limited, but where the depth of water is ten feet and over, a safe estimate of the evaporation will be about 60 per cent. of the annual rainfall in the Eastern and Middle States. In the case of Troy, we should have 36.15 + 60 per cent. = 21.6 inches. 21.6 inches divided by 12 gives 1.8 inches as the mean monthly evaporation.

This mean must be multiplied by the monthly ratios, as in the rainfall and drainage, to obtain the average monthly evaporation.

These ratios are approximately:

	Mean ratio.
January	.30
February	.35
March	.50
April	.80
May	1.45
June	1.70
July	1.85
August	2.00
September	1.45
October	.75
November	.50
December	.35

The monthly evaporation for this locality would then be closely:

	Inches evap.
January	.54
February	.63
March	.90
April	1.44
May	2.61
June	3.06
July	3.33
August	3.60
September	2.61
October	1.35
November	.90
December	.63
Year	21.6

* Evaporation measured on the west branch of the Croton River gave 24.15 mean annual, or about 50 per cent. of the rainfall. J. Jas. R. Crees, Am. Soc. Civ. Eng'rs, N. Y., July, 1874. Also, at Ogdensburgh and Syracuse, N. Y., Salem and Cambridge, Mass., ranging from 49.37 to 56 in. per annum.

From what has been stated it is evident that the evaporation from the land and water surface of the drainage area has already been taken into account in the assumption of only 50 per cent. of the rainfall as flowing in the streams, and this additional loss refers to the reservoir surfaces only.

Collecting the results, we find; the mean annual rainfall being	1.00
The mean annual of low year series	.80
Annual available flow of stream	.50
Annual evaporation from land and consumption by vegetation	.40
Annual evaporation from water surfaces	.60

In the calculation upon water works, we deal with the monthly ratios as deduced from the above annual, thus:

TABLE OF MONTHLY RATIOS, RAIN FLOW AND EVAPORATIONS.

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Ratio average monthly rain	.75	.83	.90	1.10	1.30	1.08	1.12	1.20	1.00	.95	.93	.84
Ratio average M. flow of stream	1.65	1.50	1.65	1.45	.85	.75	.35	.25	.30	.45	1.20	1.60
Ratio M. evap. from water	.30	.35	.50	.80	1.45	1.70	1.85	2.00	1.45	.75	.50	.35

AMBER.

Translated from "La Nature."

THE ancients regarded amber as a precious substance. They made ornaments of it, and engraved upon it the images of their deities. The Egyptians called it *sacal* or *checheleth*. It was one of the three aromas which formed the incense of the Tabernacle. The Philistines called it *sachaleth*, and the Phenicians *secheleth*. The Scythians called it *savium*, the Greeks *electrum*. *Chachal* signifies weeper. Amber, they said, originated in the tears of the sisters of Phaeton, who were transformed into poplars. Homer in the Odyssey calls both amber and an alloy of gold and silver, *electrum*. The palace of Menelaus was ornamented with amber.

The trade of the Phenicians in amber of the north is yet a subject of controversy. Herodotus, in his description of Europe, makes no mention of amber in the northern part.

Tacitus was the first to make mention of the amber of Prussia. It was not obtained from Prussia before the year 500, but from the peninsula of Cimbria, Jutland or the lower Elbe. The amber was carried across the continent to the shores of the Mediterranean. Hatria or Atria, founded by the Pelagians upon the shore of the Adriatic, was the center of commerce of bronze and amber, and was on the highway between occident and orient.

The Assyrians engraved ornamental designs upon amber which they called *electra* or stone of the sun. The Greeks changed this word to *electron*. Thales was the first to discover that amber, when rubbed, attracted light bodies; from this fact, as is well known, we get the word *electricity*. The Roman gladiators often carried amulets of amber, bearing the inscription "I shall conquer."

According to the ancients, amber came from Lydia, where it was formed out of the urine of the Lynx, and it was hence called *Lyncurium*. They knew nothing of its nature nor of its vegetable origin. In Byzantine art we find but few objects made in amber; but during the Middle Ages and throughout the Renaissance it was much wrought; medallions, crucifixes, reliquaries and images of the Virgin being carved in it.

The name amber was brought from the East by the crusaders, who got it from the Arabic wood *ambar*. The Spanish called it *ambrara* and the Italians *ambra*. But these names are less significant than those given by the Romans and the Germans; the former calling it *lapis ardens* and the latter *bernstein*, both names signifying a stone which burns. Modern Greeks call it *berenikenstan*.

After the treaty of Tilsit, there was accumulated at the Louvre a large collection of objects in amber of all shades, and wrought in a great variety of forms. Sicily probably furnished most of the amber to the ancients, just as at present the shore of the Baltic supplies the entire world. Although amber has been found in small quantities elsewhere, it has up to the present time been chiefly furnished from these two centers.

The theory of the origin of amber is the following: During the eocene epoch the present bed of the Baltic was occupied by an immense forest, which extended over most of the northern part of the continent.

In dredging at the bottom of the sea, there is found, at two meters' depth, thirty-two species of cone-bearing trees. These trees exuded a gum, which having been subjected to long continued pressure in the earth has become amber. The *Pinus succinus* has produced the larger proportion of it. More than twelve hundred species of fossils have been found enclosed in it. When the resin flowed from the tree it exhaled an odor which attracted flies, and these in turn drew the spiders, who, spun webs to catch them. Reptiles, pursuing their prey, were entrapped by it, and a fresh layer of resin flowing over them, they were preserved for all time. The gum remained sometines fast to the tree, but it frequently dropped upon the ground and enveloped shells, minerals, twigs, mosses and drops of salt water.

Amber is mined from slight depths in

the earth,* and is gathered by divers from the bottom of the sea. It is at times worked up on the shores of the Baltic during storms. Amber is the property of the crown. In Prussia no one can mine it on his own property without purchasing the privilege from the government, the income from this source amounting to 600,000 francs a year. One company that employs several steamboats for dredging along the shores of Konigsberg, pays about 400 thalers per day for the privilege.

The production of amber in 1874 was 175,000 kilogrammes, in masses of all qualities and of all sizes, sent to all parts of the world. The finer qualities are employed in the manufacture of mouthpieces for pipes, cigar-holders, and table and mantel ornaments of all kinds. A chandelier of amber made by Hartman, exhibited at Vienna, was bought by the Emperor of Russia for 75,000 francs.

True amber is distinguished from substances which somewhat resemble it, especially copal, by the following characters:

1st. Copal is yellow, of a more or less deep tint, but uniform throughout, and has upon its surface yellow points resembling crystallized sulphur. Amber, on the contrary, in a fragment of 12 centimeters' length will always exhibit a variation of shade.

2d. If a fragment of amber be rubbed with the finger in the palm of the hand for a few seconds, it will exhale a strong aromatic odor. Copal and the other imitations of amber have not this property.

3d. By long exposure to the air, amber sometimes parts with its essential oil, and loses its characteristic aspect. If the surface be scraped with a knife, the dust formed is heavy and falls; copal, treated in the same manner, yields a fine dust that floats in the air.

4th. Amber may be bent by smearing it with tallow, and heating it for some minutes, taking care to heat it most strongly at the places where it is expected to yield the most. The imitations will not bend.

5th. Amber is harder than any of its imitations. It is with difficulty scratched by the finger nail. Copal yields easily, especially to repeated efforts.

6th. Amber may be cut, sawed, rasped or polished, but cannot be cemented or soldered as can its imitations.

7th. To prepare varnish, copal is melted in a copper vessel over a brisk fire. At 100° C. the water contained in it forms considerable steam; the copal melts, preserving its yellow color. Amber requires a temperature of 400° to fuse it, at which point it blackens and yields an overpowering odor.

If 33 per cent. of linseed oil be added to amber it will melt at 150°.

8th. The density of amber is 1.09 to 1.11. The density of copal is 1.04, and of some false amber, 1.05.

9th. Amber yields, upon distillation, needle-shaped crystals of succinic acid. The different copals do not.

When used for cigar-holders, false amber fuses easily; copal cracks while amber resists the heat.

The chemical composition of amber is, according to Schrotter,

Carbon 78.82.
Hydrogen 10.25.
Oxygen 10.90.

* The only locality where amber is produced from underground works is at Palmnicken, on the Baltic coast. The stratum producing it is the so-called "blue earth," a loose sandstone of a bluish color, from included glauconite grains, when fresh, but weathering to a greyish green, is the lower member of the marine tertiary formation of the district. The thickness varies from 8 to 28 feet, the lower part of 7 to 11½ feet alone being worked. An area of about 160 acres has been proved by shafts and levels, the depth below the surface being about 108 feet, or 46 feet below the level of the sea. The ground being easily excavated by pick and shovel, the advance of the levels is at the rate of 3½ to 7 feet in the shift of twelve hours; but for the same reason considerable expenditure of timber is necessary to secure the sides of the workings. The levels are timbered with complete door-frame sets, at intervals of 3½ feet from center to center, the roof and sides being lined with inch planks. Great care must be exercised in securing the working faces, which, when left to themselves, even for a short time, readily give way. It is even found necessary to board up the ends of the levels on leaving them at the change of shift. The section of the levels varies with the workable thickness of the bed from 5 to 12 feet in height; the breadth is generally 4¾ feet.

For the brilliant white enamel often applied to fine cards and other purposes, the following formula is given: For white, and for all pale and delicate shades, take 24 parts by weight of paraffine, add thereto 100 parts of pure kaolin (China clay), very dry, and reduced to a fine powder. Before mixing with the kaolin the paraffine must be heated to fusing point. Let the mixture cool, and it will form a homogeneous mass, which is to be reduced to powder, and worked into paste in a paint mill with warm water. This is the enamel ready for application.

EXPERIMENTAL INVESTIGATIONS OF THE RESISTANCE OF FLUES TO COLLAPSE.

By C. R. ROELKER, Engineer Corps, U. S. Navy.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

1. CRUSHING AND COLLAPSING OF TUBES.—A hollow cylinder exposed to an external fluid pressure experiences a circumferential thrust, which has the greatest intensity at the inner surface of the cylinder. When the thickness of the cylinder is small, relatively to its diameter, the circumferential thrust may be considered, without a sensible error, as being of equal intensity throughout the wall of the cylinder, and the crushing pressure will be given with sufficient accuracy for practical purposes by the following formula, viz :

$$p=\frac{2tc\mathrm{C}}{d} \qquad (1)$$

where p=pressure in pounds per square inch, t=thickness of cylinder in fractions of an inch, d=diameter of cylinder in inches, and C=modulus of rupture for crushing of the material.

This formula applies only to the case of a tube having an accurately circular cross section, and constructed throughout of perfectly homogeneous material, which is strained equally at every portion of its wall. A tube strained by an external fluid pressure may be regarded as being in a state of unstable equilibrium, because deviations from the circular form, either existing originally in the tube or produced by the conditions under which the pressure is applied, tend to increase in an increasing ratio with the pressure till the tube gives way by collapsing. In practice the cross section of boiler flues is never exactly circular, nor is their material ever perfectly homogeneous, and they always give way by collapsing at a pressure far below that given by formula (1). Deviation from circularity and imperfect homogeneity in boiler flues are variable and uncertain elements, and this fact is sufficient to account for the discordant results obtained in many experiments on the collapse of flues under apparently equal conditions. To obtain results of real practical value, it is important that the dimensions and the construction of experimental flues should be, as nearly as possible, such as are actually used in steam boilers; and the experiments should be specially directed to the determination of the quantity of the weakening effect of such distortions as may obtain under various conditions of practice.

2. EXPERIMENTS ON THE COLLAPSE OF TUBES.—The earliest, best known, and most extensive experiments on the resistance of tubes to collapse were made by William Fairbairn, and were first described by him in a paper read before the Royal Society in 1858. (See "Philosophical Transactions," 1858, also "Useful Information for Engineers," Vol. II.)

The apparatus used by him consisted of a cast-iron cylinder 8 feet long, 28 inches in diameter and 2 inches thick, having a removable cover at each end. The cylinder communicated with a force pump. The pressure within the cylinder was measured by two spring gauges, and a safety valve did not permit the pressure to rise above 500 pounds per square inch. During the experiments this cylinder was placed upright in a pit.

The tubes experimented upon consisted, in most cases, of a single plate, 0.043 inch thick, bent to the cylindrical form upon a mandril, and riveted and brazed at the joint to prevent leakage. The ends of these tubes were riveted and brazed to rigid cast-iron discs. The diameters of these experimental tubes were 4″, 6″, 8″, 10″, and 12″, and their lengths, between the cast-iron ends, ranged between 19 inches and 60 inches. A pipe, 2½ inches in diameter, which passed through the upper cover of the cast-iron cylinder and was secured to it by nuts, placed the interior of the experimental tube in communication with the outer air. This pipe served also the purpose of bracing the upper disc of the

tubes; the lower disc was braced by a rod secured to it and to the lower cover of the cast-iron cylinder.

A few experiments were made in which the cast-iron ends of the tubes were not braced, in order to determine whether the tension produced in the tubes by bracing them had any influence on their resistance to collapse. But the results obtained were conflicting and were not regarded as conclusive by Fairbairn.

Some of the experimental tubes tested by Fairbairn were thicker than 0.043 inch, viz:

One tube (*a*) $18\frac{3}{4}$ inches in diameter and 61 inches long, and consisting of a single sheet with a lap-joint, was made of plate iron 0.25 inch thick. It collapsed at a pressure of 420 pounds.

Two tubes, both 9 inches in diameter and 37 inches long, were made of plate-iron 0.14 inch thick. One (*b*) had a longitudinal butt-joint with an outside covering plate, and collapsed at a pressure of 378 pounds. The other one (*b*) had a longitudinal lap-joint, and bore only 262 pounds.

An iron flue (*c*), consisting of three courses with lap-joints, the longitudinal seams breaking joint, was made of plates 0.125 inch thick. Its diameters were $14\frac{1}{2}$ and $14\frac{1}{16}$ inches, its extreme length $60\frac{1}{2}$ inches; the ends were of sheet-iron $\frac{1}{4}$ inch thick. The rivets, $\frac{1}{4}$ inch in diameter, were spaced $1\frac{1}{4}$ inches apart. This tube collapsed at a pressure of 125 pounds.

An iron flue (*d*), 15 inches in diameter and 0.125 inch thick, consisted of three rings connected by flanges with a plate-iron diaphragm between them. The length of the two outer rings was $21\frac{1}{4}$ inches, that of the middle ring was 17 inches. The rivets began to leak at 150 pounds, and after being re-caulked, one of the outer rings collapsed at 146 pounds. This experiment was rejected by Fairbairn, who suspected that the tube was originally defective.

A steel flue (*e*), having the same dimensions and constructed in like manner as flue (*d*), collapsed at 220 pounds in the middle ring. This flue was slightly elliptical, the diameters being $15\frac{3}{16}$ inches and $15\frac{5}{8}$ inches.

Two experiments were made with elliptical tubes, which showed the weakening effect produced by a deviation from the circular form.

From the foregoing experiments Fairbairn deduced the following empirical formula, viz.:

$$p = 9{,}675{,}600\frac{t^{2.19}}{ld} \qquad (2)$$

where the notation is the same as in formula (1), and l=length of tube in inches.

In the year 1874 experiments were made at the Navy Yard, Washington, D. C., with two large cylindrical boiler flues. (See Shock, "Steam Boilers," p. 113).

The apparatus used for this purpose consisted of a cylindrical shell 63 inches in diameter, constructed of plate-iron $\frac{5}{8}$ inch thick; the experimental flues were riveted to flanges within this shell.

For the first experiment a cylindrical flue (*f*) $76\frac{1}{2}$ inches long and 54 inches in inside diameter, was made of $\frac{1}{4}$ inch boiler iron. It consisted of two rings connected by an interior butt-strap $7\frac{3}{4}$ inches wide and $\frac{1}{4}$ inch thick. Each ring was formed of two plates with butt-joints, having interior butt-straps $7\frac{3}{4}$ inches wide and $\frac{1}{4}$ inch thick. The longitudinal seams of the two rings broke joint. All seams were double riveted. The unsupported length of the experimental flue (measured between the inner edges of rivet holes in flanges) was $71\frac{1}{4}$ inches.

One of the rings of this flue collapsed at a pressure of 105 pounds. The bulged part was pressed out and shored up, and the pressure was again applied. This time collapse took place in the other ring at a pressure of 120 pounds. The operation of forcing out and shoring up the bulge was repeated several times, the tube becoming stiffer each time. At the fifth trial collapse took place at a pressure of 186 pounds. It was found that the sheet which collapsed first was slightly less in thickness than $\frac{1}{4}$ inch, and that the flue was slightly oval, the larger diameter being $54\frac{1}{2}$ inches, and the smaller diameter $53\frac{3}{4}$ inches.

A second flue (*g*) was made of $\frac{1}{4}$ inch boiler iron, the sheets having been accurately gauged before fitting them. This flue consisted likewise of two rings, 38 inches and 39 inches long over all respectively, which were connected by flanges with a ring $\frac{11}{16}$ inch thick between

them, as in the Adamson joint. This flue was found to be perfectly cylindrical, having an internal diameter of exactly 54 inches. One of the rings collapsed at a mean pressure of 133.3 pounds, as indicated by three spring gauges. The bulged part was shored up and a second trial was made, when the other ring collapsed at a mean pressure of 130.6 pounds.

Experiments were made in March, 1878, by the Leeds Forge Company, England, with a plain cylindrical and a corrugated furnace flue, to test their relative strength when exposed to a collapsing pressure. (See "Engineering," Vol. XXV, pp. 245–260).

The plain cylindrical flue (*h*) was made of two iron plates $\frac{3}{8}$ inch thick, of unequal width, the narrower plate being about 24 inches wide. These plates were lap-welded, the welded parts being hammered down to the thickness of the adjacent portions of the plates. The actual thickness of the plates varied from 0.36 to 0.40 inch. The flue had an outside diameter of about $37\frac{1}{4}$ inches, and a length of 84 inches, with a turned collar in addition at each end, welded on, making the length $97\frac{1}{2}$ inches over all.

The test vessel was a wrought-iron cylinder, about 3 inches larger inside than the experimental flue, and strengthened with five welded rings $5'' \times 3''$, bored and shrunk on. The ends were formed by cast-iron rings, tied to each other by long bolts outside the test vessel, and bored to fit the turned ends of the flues, with a groove to receive a cupped leather packing ring. This arrangement allowed the flue to expand or contract freely.

On testing the flue with straight edges, it was found to have prominences from $\frac{1}{8}$ inch to $\frac{1}{4}$ inch high. Two of these points (marked *a*) at a distance of about four-tenths the length of the tube from one end, were selected for measuring the horizontal and vertical diameters which were found to be 36.65 inches and 37.20 inches respectively. A slight difference in the horizontal and vertical diameters was also found near the other end, where points were selected for measurements during the trial. The pressures were raised by increments of 50 pounds at first, and of 25 pounds afterward, and were taken off again after each increase. At 200 pounds pressure the flue began to come down like a blister, about 5 inches in diameter, on the top of the flue at the point *a* of the original prominence. The pressure began to fall at first slowly, then quickly, until it reached 50 pounds, when the swelling had extended 24 inches by 12 inches by 18 inches deep. The collapse took place in the narrow plate between the two welds, where the thickness was fully 0.375 inch. It was remarkable how slight were the indications of weakness preceding the collapse; a total deflection and permanent set of 0.04 inch at the point *a* being the only sign.

According to Fairbairn's formula (2), this flue should have borne about 360 pounds pressure, while it actually bore but little more than one-half that pressure. Although the tube was not accurately circular, the irregularities of form were not greater than are common in welded flues, and were less than in ordinary riveted lap-jointed flues. It may be assumed that the close proximity of the two welds was a source of weakness. It is also probable that the flue would have resisted a greater pressure, if the ends had been rigidly secured, instead of being merely stiffened by stout rings and otherwise left free to move.

In addition to the foregoing experiments, a few cases of the collapse of tubes are recorded by different writers, in which the conditions under which collapse took place were sufficiently well known to make the data valuable for comparison.

Fairbairn gives two examples of new boilers in which the flues became oval during the application of the hydraulic test pressure. (See "Philosophical Transactions," 1858). The flues (*k* and *l*) were 42 inches in diameter, $\frac{3}{8}$ inch thick, and 35 feet and 25 feet long respectively. The longer flue (*k*) became oval at a pressure of 97 pounds, and the shorter flue (*l*) at a pressure of 127 pounds.

An experiment made by Mr. Alfrey of the firm Humphreys, Tenant & Co., is cited by W. C. Unwin in a paper on the "Resistance of Boiler flues to Collapse," contained in the "Proceedings of the Institution of Civil Engineers," Session 1875–76, Part IV.). The flue (*m*) was old; originally $\frac{3}{8}$ inch thick, it had been reduced to nearly $\frac{5}{16}$ inch by corro-

sion. There were four longitudinal lap-joints in the circumference of the flue, and four circumferential lap-joints in its length. The diameter of the flue was 33½ inches, its length 360 inches, its thickness 0.34 inch. It collapsed at a pressure of 99 pounds over an arc of about one-eighth of its circumference, the collapsed part extending about one-half of the length of the flue.

An experiment is recorded in Julien et Bataille, "Machines à Vapeur," p. 240. The flue (*n*) had longitudinal and circumferential joints. Its diameter was 7.87 inches, its length 276 inches, and its thickness 0.157 inch. It collapsed at a pressure of 110 pounds.

3. Formula Deduced from the Foregoing Experiments by Different Writers.—Fairbairn thought that the results of his experiments warranted the conclusion that the resistance of cylindrical tubes to collapse varies in the inverse ratio of their diameter and length. In deducing a formula from his experiments he starts with the assumptions that the product of the collapsing pressure, per square inch, into the length and diameter of similar tubes of equal thickness is a constant quantity, and that the resistance of thin tubes to collapse follows the same law as the resistance of thin iron plates to crumpling, which varies directly as a certain power of their thickness; the number indicating this power has been found to lie between 2 and 3.

Selecting twenty experiments with tubes having a thickness of 0.043 inch, Fairbairn deduces from their results a mean value for the expression pld. It is, however, to be observed that this value varied in many cases greatly for the several tubes, and that (with one exception, viz., the 8-inch tubes) the mean value of pld for each set of tubes of equal diameter decreased as the diameter of the tubes increased, but not in a regular ratio. The greatest discrepancy existed in the results of the experiments with 12-inch tubes.

Introducing the mean value of the expression pld into an equation of the form $\frac{pld}{p_1 l_1 d_1} = \left(\frac{t}{t_1}\right)^x$ Fairbairn determines the value of the exponent x from the three experiments marked (*a*), (*b*), (*c*), in Section (2). The three values of x thus found were 2.23, 2.14 and 2.16; and taking 2.19 as the mean of these values, he uses this number as the exponent of t in his equation. In this manner he gets formula (2), viz.:

$$p = 9{,}675{,}600\frac{t^{2.19}}{ld}.$$

Fairbairn says that this "is the general formula for calculating the strength of wrought-iron tubes subjected to external pressure, within the limits indicated by the experiments; that is, provided that their length is not less than 1.5 feet, and not greater probably than 10 feet." It is, however, to be observed that the higher limit of length is arbitrarily fixed, since none of the experimental tubes exceeded 61 inches in length.

Fairbairn states that a closer approximation to the experimental results is given by the formula

$$p = 9{,}675{,}600\frac{t^{2.19}}{ld} - 0.002\frac{d}{t} \qquad (3)$$

which allows for a slight deviation from the circular form owing to the thinness of the plates.

For elliptical flues the value $\frac{2a^2}{b}$ is to be substituted for d in formula (2), where a is the greater, and b is the lesser semi-axis of the ellipse.

He recommends the use of the simpler formula

$$p = 9{,}675{,}600\frac{t^2}{ld} \qquad (4)$$

saying that for thick tubes of considerable diameter and length, this formula may be regarded as sufficiently accurate for practical purposes. It is easily seen that, by substituting the exponent 2 for 2.19, the value of p will be *increased* for thicknesses less than one inch, and *decreased* for thicknesses greater than one inch. The increase will amount to 70 per cent. when t is $\frac{1}{16}$ inch, 20 per cent. when t is $\frac{3}{8}$ inch, and 0 per cent. when t is 1 inch.

R. Wilson makes the following observations regarding Fairbairn's formula, viz.:

"Its application is limited to wrought-iron tubes above a certain length, for it can easily be shown that, if we take the crushing (crippling) strength of the ma-

terial at 12 tons per square inch, the number 15 multiplied by the thickness in inches of the tube will give the length in feet at which the crushing (crippling) strength of the tube and its collapsing strength, according to Fairbairn's rule, are equal, and any further reduction of the length will not give the increase of strength as it should do if the formula were correct. . . .

"It is probable that with ordinary tubes of the above lengths, a collapsing pressure over one-half the crushing (crippling) pressure will never be attained. . . . .

"If Fairbairn's formula is worth anything at all, we shall gain nothing in collapsing resistance to hydraulic pressure by making $\frac{3}{8}$ inch thick tubes in shorter lengths than 11 feet, seeing that this is the length given by the rule (viz. formula 2), at which the collapsing strength is half the crushing (crippling) pressure . . . The greater the thickness of the tube in proportion to the diameter, or the stiffer the tube the more will the strengthening rings tend to bring the collapsing pressure up to the crushing (crippling) pressure. A consideration of the resisting powers of the strengthening rings themselves should also not be omitted in an investigation of this matter at the high pressures we are assuming. For a $\frac{3}{8}$ inch thick tube strengthening rings, at 3-feet lengths over the fire, still serve a very useful purpose in keeping the tube in shape in the event of overheating, and in restricting the amount of distortion in the event of collapse, and should always be employed here." (See *Engineering*, June 2, 1876).

Fairbairn's formula (4) has been generally accepted as the basis of rules for ascertaining the strength of boiler flues. In some cases, however, limits are fixed to its application by a supplementary formula of the form of equation (1).

Lloyd's Register contains the following formula for the strength of circular boiler flues, viz.:

$$P=\frac{89,600t^2}{Ld}. \qquad (5)$$

The English Board of Trade prescribes the following formula for circular flues, when the longitudinal joints are welded, or made with riveted butt-straps, viz.:

$$P=\frac{90,000t^2}{(L+1)d} \qquad (6)$$

For lap-joints and for inferior workmanship the numerical factor may be reduced as low as 60,000.

The rules of Lloyd's Register as well as those of the Board of Trade prescribe further, that in no case the value of P must exceed the amount given by the following equation, viz.:

$$P=\frac{8000t}{d} \qquad (7)$$

In formula (5), (6), (7), P is the highest working pressure in pounds per square inch, t and d are the thickness and diameter in inches, L is the length of the flue in feet measured between the strengthening rings, in case it is fitted with such. Formula (5) is the same as formula (4), with a factor of safety equal to $\frac{1}{9}$. In formula (6) the length L is increased by 1; the influence which this addition has on the value of P is, of course, greater for short tubes than for long ones. By an inspection of column VI of the subjoined table, it will be seen that the limit fixed by formula (7), for formulæ (5) and (6) is by no means too low.

Grashof selected twenty-one of Fairbairn's experiments (seventeen of which were on tubes 0.043 inch thicker, and four on tubes from $\frac{1}{8}$ to $\frac{1}{4}$ inch thick), and deduced from them the following formula, viz.:

$$p=24,481,000\frac{t^{2.315}}{ld^{1.278}} \qquad (8)$$

This formula agreed, however, better with the results of the experiments with thin tubes than of those with thicker ones; Grashof devised, therefore, a second formula, which gives a close agreement with the four experiments on tubes from $\frac{1}{8}$ inch to $\frac{1}{4}$ inch thick, viz.:

$$p=1,033,620\frac{t^{2.081}}{l^{0.564}d^{0.889}}, \qquad (9)$$

where the notation is the same as in formula (2). (See "Theorie der Elasticitat und Festigkeit," von Dr. F. Grashöf, p. 328.)

Nystrom has deduced frcm Fairbairn's

experiments the following formula for the collapsing strength of flues, viz.:

$$p=\frac{4\,\mathrm{T}\,t^2}{d\sqrt{\mathrm{L}}} \qquad (10)$$

where p, t and d have the same meaning as in formula (2), L is the length in feet, and T is the tensile strength of the metal in pounds per square inch.

If we assign to T the value 50,000, and express the length of the flue in inches, equation (10) assumes the following form, viz.:

$$p=692{,}800\,\frac{t^2}{l^{0.5}d} \qquad (10a)$$

which is more convenient for comparison with formula (9.) Nystrom considers the factor of safety $\frac{1}{4}$ sufficient in applying his formula. (See "A new Treatise on Steam Engineering," by J. W. Nystrom, p. 106).

Formulæ (2), (5), (8), (9) and (10) have the common defect that they make the collapsing pressure decrease indefinitely with increase of length and *vice versa*. M. Love has deduced from Fairbairn's experiments an equation of a different form, which, reduced to English measures, is as follows, viz.:

$$p=5{,}358{,}150\,\frac{t^2}{ld}+41{,}906\,\frac{t^2}{d}+1{,}323\,\frac{t}{d} \qquad (11)$$

where the notation is the same as in formula (2). Prof. W. C. Unwin says, regarding this formula: "It is based to a certain extent on theoretical considerations bearing on the probable limit of decrease of collapsing pressure with increase of length, and it no doubt represents very closely Fairbairn's experiments."

Unwin, who had been associated with Fairbairn in making the experiments described in section (2), has published a re-investigation of them in the "Proceedings of the Institution of Civil Engineers," Vol. XLVI., Session 1875–76, Part IV., of which the following is an abstract:

He shews first that in the experiments with thin tubes, which had a uniform thickness of 0.043 inch, the originally circular tubes bent during collapse into figures consisting of acres of alternately convex and concave curvatures, and that the number of arcs increased as the ratio of length to diameter decreased.

Considering a strip of a tube 1 inch wide, the total uniformly distributed load on one arc of such a strip is $p\,\lambda$ pounds, when t is the length of the arc; and the resistance to bending is given by the equation

$$p\lambda=\tfrac{4}{3}f\frac{t^2}{\lambda}, \text{ and } p=\tfrac{4}{3}f\frac{t^2}{\lambda^2} \qquad (12)$$

Consequently the collapsing pressure necessary to produce bending varies inversely as the square of the length of the arcs into which the tube divides; and the strength of the tube must depend on the number of arcs into which the tube divides. From the results of 19 experiments with thin tubes Unwin finds the equation

$$\lambda=0.6375\,l^{0.45}d^{0.08} \qquad (13)$$

which gives the best average value for the length of the arcs into which the tubes divided during a collapse.

Unwin assumes that the metal of the flue is in the same condition as a straight column of the length πd, subjected to a compression of the intensity

$$\mathrm{T}=\frac{pdb}{2} \qquad (14)$$

where b is the length of a slice of the flue, and d its diameter. He then applies the laws of resistance of long columns to the investigation of the strength of flues. According to Euler's theory we have

$$\mathrm{T}=\pi^2\frac{\mathrm{IE}}{\lambda^2} \qquad (15)$$

where I is the moment of inertia of the section of the column about an axis, through its center of figure, and perpendicular to the plane of bending; E is the modulus of elasticity of the material; T is the greatest thrust consistent with stability. For a rectangular section,

$$\mathrm{I}=\frac{bt^3}{12}; \quad \text{then}$$

$$\mathrm{T}=\frac{\pi^2\mathrm{E}}{12}\,\frac{bt^3}{\lambda^2} \qquad (16)$$

Putting E=28,500,000 we have

$$\mathrm{T}=23{,}440{,}000\,\frac{bt^3}{\lambda^2}; \qquad (17)$$

and combining equations (14) and (17), we get

$$p=\frac{46{,}880{,}000\,t^3}{d\lambda^2} \qquad (18)$$

Introducing into this equation the value of $t=0.043$, we find

$$\lambda=\frac{61.05}{\sqrt{pd}} \qquad (19)$$

Combining equation (19) with equation (13), we obtain for the collapsing pressure of tubes 0.043 inch thick, the following formula, viz.:

$$p=\frac{9170}{l^{0.9}\ d^{1.16}} \qquad (20)$$

Fairbairn's formula for the same tubes, is

$$p=\frac{9838}{l\ d} \qquad (21)$$

which is not widely different, though obtained in an entirely different manner.

Unwin next defines the limits of length and thickness within which the formula is applicable. He finds, $l_{\max.}=6.7\ d^2$ nearly; $l_{\min.}=4468\ \frac{t^{2.22}}{d^{0.18}}$. The two limits coincide when $t=\frac{d}{19}$. For greater values of t the formulæ cease to be applicable.

Assuming that the preceding investigations indicate that the collapsing pressure of tubes is given by an equation of the form

$$p=c\frac{t^n}{l^{0.9}\ d^{1.16}}$$

and, taking the experiments on thin tubes as a starting point of the comparison, Unwin deduces values of the factor c and the exponent n from a number of experiments with thicker tubes, combining the results obtained with tubes of similar construction.

From two experiments with tubes made with a *longitudinal lap-joint*, [marked (a) and (b), in section 2], he deduces the formula

$$p=7{,}363{,}000\frac{t^{2.1}}{l^{0.9}d^{1.16}} \qquad (22)$$

From one experiment with a tube having a *longitudinal butt-joint*, [marked (b) in section 2], he gets the formula

$$p=9{,}614{,}000\frac{t^{2.21}}{l^{0.9}\ d^{1.16}} \qquad (23)$$

From five experiments with tubes having *longitudinal and circumferential joints* [marked (c), (k), (l), (m) and (n), in section 2], he derives the formula

$$p=15{,}547{,}000\frac{t^{2.35}}{l^{0.9}\ d^{1.16}} \qquad (24)$$

In order to make the latter formula convenient for arithmetical calculations, he gives it the form

$$p=15{,}547{,}000\ \frac{t^2}{ld}\cdot\frac{\alpha}{\beta\gamma} \qquad (24a)$$

where $\alpha\ \beta\ \gamma$ are variable co-efficients, the values of which, corresponding to certain values of t, l and d, are given by him in a table adjoined to his investigation.

Unwin says, regarding these formulæ: "It will be seen that the indices of the thickness do not differ more than would be anticipated from Hodgkinson's value. It is believed that the separation of the experiments, here adopted, into sets of similar experiments leads to more reliable results than the mixing up of heterogeneous experiments to obtain average values of constants. In applying these formulæ to practical cases, it ought to be borne in mind that slight deviations from the circular form may greatly affect the value of λ, and much reduce the strength of the flue."

Theodore Belpaire has made an attempt to develop a formula for the strength of flues from experimental data, from which the variable and uncertain element of strength due to circularity of form has been eliminated. He starts with the idea that flues derive their main strength from the rigid fastenings of their ends. Considering the flexure of a narrow strip of a tube cut parallel to its axis, he finds that the bending forces are so insignificant that they may be neglected without sensible error; and he bases, therefore, his investigation on the equation giving the greatest shearing forces which exist at the rigidly secured ends of the loaded strip, viz.:

$$S=\frac{p\ l}{2\ t} \qquad (26)$$

The highest value of S consistent with stability is to be deduced from experimental data. Belpaire rejects all experiments with circular flues, and uses those made with elliptical ones, because in the latter cases the relation existing between the strength and the form of the transverse section can be deduced with some degree of certainty.

Calling D the greater and X the lesser

diameter of the ellipse, he represents its eccentricity by

$$e=\frac{D-X}{D} \qquad (27)$$

S is evidently a function of the eccentricity, and may be expressed with sufficient accuracy by an equation of the form

$$S=a+Be+Ce^2. \qquad (28)$$

Since the resistance to flexure approaches zero, and consequently S=0, when E=1, and since, on the other hand, S=a maximum, when e=0, the equation (28) can be put under the following form, viz.:

$$S=A\,(1-e^2.) \qquad (29)$$

S (and consequently A) is likewise a function of $\frac{t}{d}$, and an approximate value for A may be deduced from an equation of the form

$$A=m+n\left(\frac{t}{d}\right)+q\left(\frac{t}{d}\right)^2 \qquad (30)$$

Since S=0, when $\frac{t}{d}$=0, we must make m=0. Introducing this value into equation (30), and combining equations (29) and (30) we get the equation

$$S=\left\{n\left(\frac{t}{d}\right)+q\left(\frac{t}{d}\right)^2\right\}(1-e^2) \qquad (31)$$

Belpaire deduces values for n and q from two experiments by Fairbairn on elliptical tubes. Introducing the values thus found into equation (31), and making e=0, he gets the following expression for S applicable to tubes of a circular cross-section, viz.:

$$S=1{,}713{,}576\left(\frac{t}{d}\right)-28{,}446{,}200\left(\frac{t}{d}\right)^2 \qquad (32)$$

Introducing this value of S into formula (26), we get

$$p=3{,}427{,}152\frac{t^2}{ld}-56{,}892{,}400\frac{t^3}{ld^2} \qquad (33)$$

Applying this formula to a number of examples of tubes collapsed under known conditions, Belpaire finds that the actual collapsing pressures were from 1.05 to 4.15 times as great as the pressures given by formula (33). These variations he ascribes to the influence of the uncertain elements of stiffness, circularity of form and homogeneity of material, which, he avers, should not be allowed to influence a formula of this kind. Since, however, all tubes derive more or less additional strength from these causes, he considers one-quarter a sufficiently large factor of safety in proportioning flues by means of formula (33). (See "Note sur la résistance des tubes pressées de l'extérieur," par Théodore Belpaire, in "Annales du Génie civil," Mars, 1879).

Equation (33) may be written as follows, viz:

$$p=3{,}427{,}152\frac{t^2}{ld}\left(1-16.6\,\frac{t}{d}\right) \qquad (33a)$$

The factor $(1-16.6\frac{t}{d})$ becomes zero, and consequently p=0, when $16.6\frac{t}{d}=1$, or $d=16.6\,t$. This indicates that the formula is, at best, applicable only within certain limits, which, however, have not been determined.

D. K. Clark, in his "Manual of Rules," etc,, p. 696, gives the dimensions of six flues, selected from the reports of the Manchester Steam-Users Association. 1862–69, which collapsed while in actual use in boilers. These flues varied from 24 to 60 inches in diameter, and from $\frac{3}{16}$ to $\frac{8}{8}$ inch in thickness. They consisted of rings of plates riveted together, with one or two longitudinal seams, but all of them unfortified by intermediate flanges or strengthening rings. At the collapsing pressures the flues experienced compressions ranging from 1.53 to 2.17 tons, or a mean compression of 1.82 tons per square inch of section. From these data Clark deduced the following formula "for the average resisting force of common boiler flues," viz :

$$p=t^2\left(\frac{50{,}000}{d}-500\right) \qquad (34)$$

where p is the collapsing pressure in pounds per square inch, and d and t are the diameter and thickness expressed in inches.

It is assumed that the flues are not strengthened by rings. The influence of length on the strength of flues Clark calls an uncertain element; it is, however, a very important one, as proven by Fairbairn's experiments, and for this reason the formula is not generally applicable.

The following table contains the data of all experiments on the collapse of flues having thickness of one-eighth inch

and more, of which a reliable record could be obtained, and which are described in section 2 of this article; also the collapsing pressures calculated by means of the different formulæ, of which an account has been given. In comparing the calculated with the actual collapsing pressures, for the purpose of estimating the reliability of the several formulæ, it is, of course, necessary in each case not to take into consideration those experiments from which the formula was deduced.

In Fairbairn's formula (2) the index number of the power of t was deduced from the results of experiments Nos. 1, 2 and 6. Leaving these experiments out of consideration, only one experiment, viz., No. 11, shows a tolerably close agreement between the actual and the calculated collapsing pressures; all other experiments give too large a value for flues having a length less than 60 inches, and too small a value for flues having a length of 276 inches or more.

Fairbairn's approximate formula (4) gives in every case a larger value for the collapsing pressure than formula (2), as previously explained. It is easily seen that the close agreement between the actual and calculated results in the case of experiments Nos. 9 and 10 is purely accidental.

Grashof's formula No. (9) gives in every case much too high a value of p, except in experiments Nos. 1, 2, 5 and 6, from which the formula was deduced.

Nystrom's formula (10) was deduced from Fairbairn's experiments, but it is not stated which of them were used. As in no case the tensile strength of the metal of which the experimental flues were made has been recorded, an average value of T=50,000 in the case of iron flues, and of T=70,000 in the case of the steel flue, has been assumed. On the whole, this formula gives a closer agreement of the calculated with the actual collapsing pressures in experiments on flues of every description than any of the other formulæ.

Love's formula (11) gives in every case too large a value, probably because it was deduced mainly from Fairbairn's experiments with very thin tubes.

Unwin's formulæ (22), (23), (24), applied to other experiments than those from which they were deduced, give too large results, except in the case of No. 11, where the agreement is tolerably close.

Experiments Nos. 4 and 5 were rejected by Fairbairn and Unwin, but perhaps not on sufficient grounds. Nystrom's formula (11) agrees quite well with the results of these experiments.

Belpaire's formula (33) gives in only one case a close agreement with the actual results of the experiments; and the degree of agreement varies widely in the other cases.

4. Insufficiency of the Above-Described Experiments.—It will be noticed that many of the formulæ given in the previous section, though deduced mostly from the same set of experiments, and being similar in form, assign very different values to the influence of length, diameter and thickness of tubes on their resistance to collapse, and that most of them give very discordant results.

The differences in the two formulæ, (8) and (9), deduced by Grashof from Fairbairn's experiments, illustrate plainly the fact that the numerous experiments on very thin tubes are of relatively little value for determining the strength of flues used in steam boilers. In fact, all those formulæ which are based principally upon the experiments with tubes 0.043 inch thick, are very defective. This remark applies specially to Fairbairn's formula (2), to Love's formula (11), and also to Unwin's formulæ (22), (23) and (24). Unwin recognized the fact that it was hazardous to apply to thick tubes the rules relating to the influence of length and diameter on the strength deduced from very thin tubes; but he was compelled to do so by the paucity of available experiments. He derived the numerical factor and the index number of t in formula (22) from *two* experiments, those in formula (23) from *one* experiment, and those in formula (24) from *five* experiments, on tubes from $\frac{1}{8}$ inch to $\frac{3}{8}$ inch thick. There are not a sufficient number of experiments extant to test fully the value of his formulæ.

It should be especially noticed that *not a single* experiment has been made on tubes representing exactly the ordinary construction and dimensions of cy-

TABLE SHOWING DIMENSIONS, AND ACTUAL AND CALCULATED COLLAPSING PRESSURES OF FLUES.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII	XIII.	XIV.	XV.	XVI.	XVII.	XVIII.	XIX.	XX.	XXI.	
							Calculated Collapsing Pressure.														
Number of experiment.	Length in inches. l	Diameter in inches. d	Thickness in inches. t	Ratio of length to diameter. $\frac{l}{d}$	Crushing pressure in pounds per square inch of section. $\frac{pd}{2t}$	Actual collapsing pressure in pounds per square inch. p	Fairbairn's formula (2.) p_2	Ratio. $\frac{p_2}{p}$	Fairbairn's formula (4.) p_4	Ratio. $\frac{p_4}{p}$	Grashof's formula (9.) p_9	Ratio. $\frac{p_9}{p}$	Nystrom's formula (10.) p_{10}	Ratio. $\frac{p_{10}}{p}$	Love's formula (11.) p_{11}	Ratio. $\frac{p_{11}}{p}$	Unwin's formulæ (22), (23), (24.) p_{22}, p_{23}, p_{24}	Ratio. $\frac{p_{22}}{p}$ *ecc*	Belpaire's formula (33.) p_{33}	Ratio. $\frac{p_{33}}{p}$	Remarks.
1	61	18.75	0 25	3.5	15,750	420	406*	0.97	529	1.26	420*	1.00	296	0.70	450	1.07	331*	0.79	146	0.35	Longitudinal lap-joint, Fairbairn's experiment [*a.*]
2	37	9	0.14	4.1	12,150	378	392*	1.04	569	1.51	319*	0.85	248	0.66	427	1.13	378*	1.00	150	0 40	Longitudinal butt joint, Fairbairn's experiment [*b.*]
3	37	9	0.14	4.1	8,421	262	392	1.49	569	2.17	319	1.22	248	0.95	427	1.60	359*	1.37	150	0.57	Longitudinal lap-joint, Fairbairn's experiment [*b.*]
4	21.25	15	0.125	1.41	9,000	150	319	2.13	474	3.16	219	1.46	157	1.04	316	2.11	258	1.72	144	0.96	Longitudinal lap-joint, Fairbairn's experiment [*d.*]
5	17	15.19 × 15.63	0.125	1.1	13,754	220	372	1.69	553	2.51	240*	1.09	235	1.07	368	1.67	301	1.37	175	0.79	Longitudinal lap-joint (steel), Fairbairn's experiment [*e*]
6	60.5	14.7	0.125	4.1	7,350	125	114*	0.92	170	1 36	124*	0.99	95	0.76	150	1.20	131*	1.05	52	0.41	Longitudinal & transverse joints, Fairbairn's experiment [*c.*]
7	420	42	0.375	10.0	5,433	97	64	0.65	77	0.79	160	1.65	113	1.17	195	2.01	88*	0.91	23	0.24	Longitudinal & transverse joints [*k.*]
8	300	42	0 375	7.1	7,112	127	90	0.71	108	0.85	194	1.53	134	1.05	212	1.67	120*	0.94	32	0.26	Longitudinal & transverse joints [*l.*]
9	360	33.5	0.34	10.7	4,877	99	76	0.76	93	0.94	175	1.76	126	1.27	209	2.12	105*	1.06	27	0.28	Longitudinal & transverse joints [*m.*]
10	276	7.87	0.157	33.8	2,757	110	77	0.70	110	1.00	147	1.36	130	1.19	219	1.99	116*	1.06	26	0.24	Longitudinal & transverse joints [*n.*]
11	71.25	53.75 × 54.5	0.25	1.3	11,445	105	118	1.13	156	1.48	149	1.42	94	0.90	140	1.34	124	1.18	51	0.49	Long'tud'l & transverse j'nts [*f.*]
12	36	54	0.25	0.67	14,105	130.6	239	1.84	311	2.38	225	1.72	133	1.02	227	1.74	175	1.34	101	0.77	Longitudinal butt-joints [*g.*]
13	84	37.25	0.375	2.25	9,933	200	361	1.80	435	2.17	442	2.21	285	1.42	414	2.07	307	1.54	128	0.64	Longitudinal butt-joints (welded) [*h.*]

*Experiment used in deducing formula.

lindrical furnace flues, so extensively used at the present day in marine boilers. The two flues, marked (*f*) and (*g*), used in the experiments made at the Washington Navy Yard in 1874 (See Section 2 and Nos. 11 and 12 in the table), were made of very thin metal relatively to their diameter. The flue used in the experiment made by the Leeds Forge Company (See Section 2, and No. 13 in the table), while being otherwise an exact representation of a cylindrical furnace flue, was not secured at the end; and there is no doubt that this circumstance altered materially the conditions of the experiment, and was one cause of the low collapsing pressure of this tube.

The influence of deviations from the circular form has never been fully investigated. Fairbairn's experiments proved the weakness of lap-joints; but they comprise only two experiments with elliptical flues, which furnish insufficient data for the construction of a formula as attempted by Belpaire.

There are no records of tests made to determine the quality of the metal used in the construction of any of the experimental tubes.

The behavior of the tubes under increasing pressures during the experiments has been recorded only in a single instance, viz., in the experiment made by the Leeds Forge Company, and then only imperfectly.

While no reliable rules for proportioning and determining the strength of furnace flues can be deduced from the data furnished by the experiments heretofore made, these will be useful for checking the results obtained in future experiments—made with a special view toward determining the resistance of tubes representing the dimensions, construction and conditions of working of furnace flues as they occur in practice. When flues collapse during actual use in boilers the circumstances accompanying collapse and the immediate causes of the failure are seldom known sufficiently well to make such accidents the basis of accurate calculations.

5. Recommendations Regarding Future Experiments on the Resistance of Furnace Flues to Collapse.—Exhaustive experiments on the resistance of furnace flues to collapse should have for their object the determination of the influence which the following elements have on the strength of flues, viz.: 1. The length, diameter and thickness, with the proportions usual in practice. 2. Various modes of construction, *e. g.*, the use of riveted butt-joints and of welded joints for the longitudinal seams, different styles of circumferential joints, and different methods of securing strengthening rings. 3. The kind and quality of the metal of which the flues are made, viz., iron or steel, and especially the ductility and limit of elasticity of the metal. 4. Various elements of weakness common in practice, especially deviations from the circular form, and local weaknesses produced by corrosion and by overheating of the plates.

The usual dimensions of furnace flues of marine boilers may be assumed to vary between the following limits, viz., the length between 30 inches and 84 inches, the diameter between 30 inches and 42 inches, the thickness between $\frac{1}{4}$ inch and $\frac{9}{16}$ inch.

A *first series* of experiments should be made with a special view toward determining the influence of the several dimensions, viz, length, diameter and thickness, on the strength of flues. For this purpose each dimension should be varied at least three times within the above-given limits, under otherwise identical conditions of dimensions, quality of material and mode of construction. All these flues should be made, as nearly as possible, circular; they should be constructed in the manner which is most common in practice, and can be best relied upon to give uniform results; that is to say, riveted butt-joints with internal straps should be used for the longitudinal seams. The same material should be used in this whole series of experiments, and it should be of the kind commonly used in the construction of furnace flues, viz., *Extra Firebox Iron*, or a similar brand, the ductility and limit of elasticity of which have been carefully determined in the testing machine.

A *second series* of experiments should be made with flues, circular in cross section, and identical in every respect with the flues used in the first series of experiments, with the exception of either the mode of construction, or the material, or both; that is to say, some flues

are to be made of steel or of different brands of plate iron of known quality; others are to be made with welded joints instead of riveted butt-joints at the longitudinal seams; in others, different kinds of circumferential joints connecting the several sections of the flues may be used. At least two experiments should be made with each kind of material and style of joint, but the dimensions of the flues may be varied in each experiment.

A *third series* of experiments should be especially directed to the investigation of the weakening effect of deviations from the circular form. This subject should receive the most careful attention, as an accurate determination of this weakening influence will enable us to proceed intelligently in assigning a co-efficient of safety, to be used in connection with formulæ derived from the first and second series of experiments, and may likewise explain any apparent anomalies in the results of these experiments. Slight deviations from the circular form are unavoidable in furnace flues, and will occur also in the experimental flues of the first and second series; they must be carefully measured and recorded in all cases. In practice, deviation from the circular form may be due to the following causes, viz.: 1. The mode of construction, *e. g.*, when lap-joints are used; in this case the amount will depend on the thickness of the plates. 2. Inaccuracy of workmanship frequently causes a difference of $\frac{1}{2}$ inch or $\frac{3}{4}$ inch in the diameters of flues of ordinary dimensions. 3. Distortion under pressure in consequence of want of homogeneity of the material, or of unequal distribution of strains. No numerical value can be assigned to distortion due to these causes. 4. Distortion due to unequal expansion in consequence of difference of temperatures. The increase of diameter, due to a uniform increase of temperature, such as may occur in practice, is small. The diameter of a 36-inch tube will increase about $\frac{1}{8}$ inch, when the temperature is raised 550 degrees Fahrenheit. Local distortions, due to overheating of plates in places where the accumulation of scale prevents the ready transmission of heat to the water, will vary greatly in amount under different conditions.

To determine the weakening effect of these causes, experiments should be made with flues constructed in the same manner and of the same material as the flues of the first series of experiments. The ratio of thickness to diameter should be likewise in them approximately the same, but their cross section should deviate a known amount from the circular form. In determing this deviation it is not sufficient to measure the differences of diameters, but the actual curves of the cross sections should be accurately measured. To make the results of these experiments comparable, at least two values of sufficient magnitude should be given to these deviations from the circular form in otherwise identical flues.

A *fourth series* may comprise experiments with flues made of old plates corroded to a greater or less degree in an irregular manner, or showing signs of blistering and lamination. In others local weaknesses and unequal distribution of strains may be produced by the application of intense heat. For the latter purpose gas jets, impinging on the crown of the flue may be used, the external cylinder having been filled only partly with water so that the space over the top of the flue is filled with compressed air, which permits the overheating of the plates.

From every plate used in the construction of the experimental flues two specimens should be cut, one lengthwise and one crosswise the fiber, for testing the ductility and the limit of elasticity of the metal in the testing machine. These specimens should have a uniform width, and a length of 8 inches between the shoulders, this being the standard length of test-specimens adopted by the French and English Governments. The elongation of the specimens under increasing strains, after the limit of elasticity has been passed, should likewise be carefully measured and recorded. If possible, these tests should be repeated at high temperatures.

The thickness of each plate must be accurately gauged and its soundness must be carefully tested before it is used in the construction of flues. If the flues fail by local distortion, the bulged plates should be drilled or cut and carefully examined for hidden defects.

The ends of the flues should be securely fastened, as in actual boiler practice.

The apparatus used in the experiments made at the Washington Navy Yard, in 1874, may serve as a model for futuer experiments. (See Section 2 and Shock "Steam Boilers," p. 113).

The pressure should be applied gradually to the experimental apparatus by means of a force pump. After each increase of 50 pounds, or 25 pounds as the limit of strength is approached, the tube is to be accurately gauged at several places; then the pressure is to be released, and the flue is to be gauged again to determine whether any permanent set has taken place. The element of time deserves particular notice in making these experiments. Especial care is to be taken in every case to maintain each increase of pressure a sufficiently long time to let it produce its full effect. A complete record of all variations in the form of the tubes under pressure, and of all conditions and incidents of the experiments is to be kept.

The form of the tube should be determined before commencing the experiments as well as during its progress, by measurement from a fixed central axis by means of an adjustable radial arm, movable along and around this axis.

While complete series of experiments, as above described, can be undertaken only under the auspices of the Government or other public institution, each single experiment conducted by private parties will be of great value if the above suggestions are followed, and a full record of accurate observations is kept and made public.

ELECTRIC LIGHTING: THE DIVISION AND REGULATION OF THE ELECTRIC CURRENT.*

From Sawyer's "Electric Lighting by Incandescence."

To announce a new work on electric lighting in these days is to excite anew the public interest in a subject which at no time within the last two years has failed to elicit the absorbed attention of all classes. The opinion of an expert in matters relating to the present and probable future condition of this very practical question will, in some measure, satisfy the demand for better knowledge of the problems which the inventors have of late been striving to solve.

The new work of Mr. Sawyer will be found valuable, inasmuch as it describes with exceptional clearness the character of the difficulties to be overcome, and the methods devised by different inventors to meet the requirements of in-door lighting by electricity.

After describing the different types of generators and of incandescent lamps, the author proceeds to the elucidation of the all-important question of the "Division of the Current and Light."

We quote here from chapters IX. and X., the latter being devoted to regulators and switches:

"Division of Current and Light.—Much has been written concerning the loss of light by subdivision of the current, and this has been variously estimated, sometimes as the square and sometimes as the cube of the number of lights among which the current is divided. Upon what data and with what purpose these estimates have been made it is difficult to conceive, for they have no foundation in practical fact.

If to the conducting pipe of a gas system a given volume of illuminating gas is supplied in a given time, and all this gas is consumed in a single burner in order to yield a given light, when we divide the volume of gas thus supplied among two or more burners the total light produced may, indeed, have greatly decreased. We do not, however, supply gas in this manner, but the volume of gas supplied is in direct proportion to the number of burners to be fed.

What is true of gas is equally true of electricity. If a fixed volume of current,

* Electric Lighting by Incandescence and its application to Interior Illumination; by William Edward Sawyer. New York: D. Van Nostrand.

sufficient for one light, is furnished to a single lamp the maximum effect is produced, and if we divide this fixed volume among two or more lamps the total effect is greatly diminished; but to suppose that such a division is contemplated is to suppose a similar operation in the case of gas, and criticism of statements based upon such a supposition is, simply, waste of time and labor. When we increase the number of lights in circuit, we increase the volume of current in proportion; and the power of the total light is increased in proportion; and the energy expended in producing the light, and therefore its cost, is increased in proportion.

Without at this time entering into any considerations of the fact that the current from a single generator of electricity has repeatedly been divided between from two to two hundred incandescent burners, the operations of the Brush system of voltaic-arc lighting set at rest the question of economical subdivision.

Two machines of the Brush type are selected for comparison, viz., the six-light and the sixteen-light machines, both of which are in practical use throughout the United States—the light of each of the twenty-two lamps being of the same intensity as that of each and every other lamp.

With the six-light machine the total driving power absorbed per minute is 236,940 foot-pounds, or 39,490 foot-pounds per lamp.

With the sixteen-light machine the total driving power absorbed is 618,090 foot-pounds, or 38,630 foot-pounds per lamp.

It is thus clearly shown that for each lamp added to the circuit there is an expenditure of power in proportion to the additional work, the somewhat diminished power per lamp expended in the sixteen-light machine being mainly due to the element of friction, in which the percentage of absorption of power is less in large than in small generators.

As a matter of fact, there is no limit to the divisibility of the electric current. While the possibility and the impossibility of its divisibility become from time to time the subject of controversial discussion, practical subdivision is a daily concomitant of every telegraphic circuit. Even in telephonic transmission the current generated is divided between the transmitter and the receiving instrument, and in some large telegraphic stations the wires radiate from a single generator in several directions, and in the circuit of each of these wires, at towns and cities along their route, there is placed a greater or less number of instruments, each of which is energized from the source common to all of them; and the proportion of current supplied to each instrument is made substantially the same in all cases, by making the resistance of the instruments uniform. The strength of the current thus supplied is, of course, inadequate to the operation of an electric-lighting system, as an ordinary main-line telegraphic battery is inadequate to the operation of even a single voltaic-arc lamp; but if we increase its strength proportionately, and for each telegraphic instrument substitute an electric lamp, we as certainly accomplish subdivision of the electric-light current as subdivision of less powerful currents is accomplished with telegraphic instruments. Indeed, the laws which govern the supply of gas to gas burners and the supply of electricity to electric burners are daily recognized and availed of in the operation of telegraphic circuits.

For instance, in operating a given number of telegraphic instruments in series, we employ a given number of cells of battery. Suppose, now, that we double the number of instruments and the resistance of the circuit; all the instruments, since they receive proportionately less current, become practically inoperative, and we increase the number of cells, and therefore the electro-motive force of the battery, in proportion to the additional work required, which is that of overcoming the added resistance. If, on the other hand, we divide the current from a single generator among two or more lines, each including a number of instruments in series, we require a current of greater quantity; hence we increase the size of the elements of the generator.

In electric lighting there are five methods of dividing the current from a single generator of electricity:

1. The series system. Passing the current seriatim through the lamps, as in the Brush system of lighting.

2. The multiple system. Connecting

the poles of the generator with two parallel wires, and placing each lamp in a branch running from wire to wire, as in the Edison and Maxim systems.

3. The multiple-series system. Connecting the poles of the generator with two parallel wires, and placing a number of lamps in each branch running from wire to wire, as in the Sawyer-Man system.

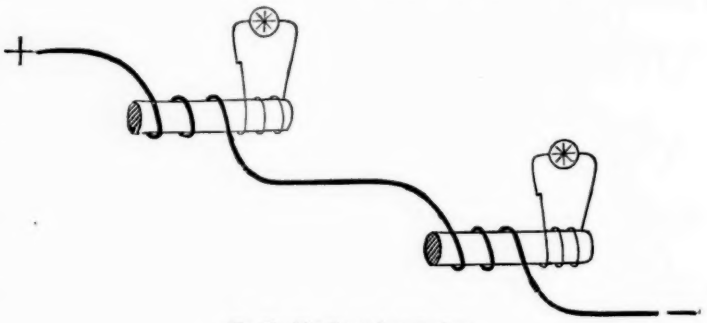


Fig. 66. The Secondary System.

4. The series-multiple system. Connecting one pole of the generator to a wire which, at the point at which light is needed, divides into a number of strands, each containing a lamp or lamps, and which strands again combine together in a single wire, which runs to the next point of division; and so on indefinitely, returning finally to the other pole of the generator; as in the Sawyer system.

Fig. 67. Lamps in Series.

5. The secondary system. Passing the main current through the primary wire of an induction coil, in the circuit of the secondary coil of which the lamp is placed (Fig. 66).

Alternating or intermittent currents are employed, and, owing to the reactive earth inductions, this principle cannot be applied over any considerable territory. Moreover, it involves loss of power in the heating of the iron core of the induction apparatus, is an indirect application of power, and, in electric as in all other forces, direct application is found to be the most economical. *

How to practically divide the current from a single source among a large number of incandescent lamps has been considered a debatable question. We shall content ourselves with glancing at the results which must follow an extension of the four systems which appear to be suitable, assuming that in each case 1,000 lamps and 10,000 lamps are to be operated upon a single circuit. Where there is a limited number of lamps either the series, the multiple, the multiple-series or the series-multiple systems may be employed with about equal advantage; but where the number of lamps is increased to hundreds or thousands, as must be the case in any general application of electric lighting, considerations novel in character rapidly present themselves.

Taking first the series system (Fig. 67), in which the current traverses the lamps seriatim, and assuming that interruption of the circuit of any lamp will not interrupt the entire circuit, we have with 1,000 lamps a resistance, not includ-

* As recently as 1877-78 several claimants to this method of subdivision have appeared, but the system was patented in England by Harrison in 1857 (Letters Patent 588), under the title, "Improvements in obtaining Light by Electricity;" and it is not quite clear that Harrison was the original inventor. The Harrison patent expired in 1871, unless the Government taxes were unpaid, in which case it must have expired at an earlier date.

ing the internal resistance of the generator or the external resistance of the main conductor, of 1,000 ohms. With 10,000 lamps the resistance becomes 10,000 ohms.

Can this resistance be overcome by any practicable construction of generator?

The electro-motive force of current necessary to operate an incandescent lamp of one ohm resistance is, as to the lamp, such as will yield a voltaic arc $\frac{1}{32}$ of an inch in length. The electro-motive force necessary to overcome the resistance of 1,000 lamps is, therefore, that which will yield an arc of $31\frac{1}{4}$ inches in length, or with 10,000 lamps an arc 26 feet in length.

Assuming its existence, we need not describe the probable effect of a current of such tension upon the person of any one unfortunate enough to come in contact with the conductor, or the difficulty of insulating the conductor at all; but will simply say that no generator could be constructed around the commutator of which the current generated would not short-circuit. In other words, the current could not be produced exterior to the machine.

With the multiple system (Fig. 68) the conditions are in some respects reversed. The danger of a short circuit occurring in any branch is avoidable, and the electro-motive force of current being low, there would appear to be no difficulty in insulating the main conductors. The questions arising in the operation of this system relate particularly to the generator.

Assuming that the generator is so constructed as to give a useful effect in the external circuit of any percentage of the total current, say 75 per cent., and that the resistance of the lamp used is 200 ohms instead of one ohm (for comparison with a low-resistance lamp would obviously be unfair to a system in which lamps of high resistance only are employed), the internal resistance of the generator would be 66.66 ohms, and the total resistance of the circuit 266.66 ohms. Suppose now that we add another lamp to the circuit of the machine; we reduce the external resistance to 100 ohms, because the current has now two paths to traverse, each of 200 ohms resistance. The total resistance of the external circuit becomes 166.66 ohms, and $\frac{66.66}{166.66}$ of the current is wasted in the machine. Let the number of lamps be ten; then we have an external resistance of 20 ohms, and a total resistance of 86.66 ohms. We thus obtain in the external circuit only $\frac{20}{86.66}$ of the current generated, or about 23 per cent. Extending the calculation to one hundred lamps, thus making the external resistance two ohms, we are able to utilize less than 3 per cent. of the current generated.

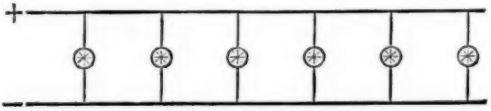


Fig. 68. Multiple Circuit.

In order to be able to operate one hundred lamps with a utilization of 50 per cent. of the whole current, we must, therefore, reduce the internal resistance of the generator to two ohms; with one thousand lamps, its resistance must be reduced to two-tenths of one ohm; and with ten thousand lamps, to two one-hundredths of an ohm. In order that there may be but little loss in the main conductors leading from the generator, they must be of large size, for the resistance of a copper conductor weighing four pounds per foot is substantially four one-hundredths of an ohm per mile; and as there are two mains, the total resistance of the conductors, costing, as bare copper at 30 cents per pound, $12,672, is eight one-hundredths of an ohm. With such a conductor, the total resistance of the circuit of 1,000 lamps would be .48 of an ohm, divided as follows: Generator, .2; mains, .08; lamps, .2. There would thus be wasted in the generator $41\frac{2}{3}$ per cent. of the current, and in the

mains $16\frac{2}{3}$ per cent.; utilized as light, $41\frac{2}{3}$ per cent. To bring the utilization up to between 49 and 50 per cent., the mains must weigh 32 pounds per foot, and will therefore cost $101,376. The respective resistances will then be: Generator, .2; mains, .01; lamps, .2 of an ohm.

In corresponding ratio the size of one mile mains for 10,000 lamps must be increased, if we desire to approach a realization in light of even 50 per cent. of the current generated, and the internal resistance of the generator must be reduced to two one-hundredths of an ohm. We shall not pause to consider the character of a generator of the required power and of so low an internal resistance, for we have no practical data upon which to base an opinion. The production of a generator of the resistance given, combined with the capacity indicated, is at all events possible. Concerning the requirements of any multiple-circuit generator, however, we are enabled to see that it must be one of multiple induction, the coils of which shall be automatically joined together to form a multiple-internal circuit, which shall both increase the quantity of the current generated and reduce the internal resistance of the generator, in proportion as the number of lamps in the external circuit is increased and the external resistance reduced. In the mechanical construction of such a generator there is a wide field for study and experiment.

Referring now to the multiple-series system (Fig. 69), it is evident that, in operating 1,000 lamps of 200 ohms resistance each, there may be one hundred branches across from main to main, and in each branch ten lamps, which would make the external resistance of the circuit, not including that of the mains, 20 ohms $\left(\frac{10\times200}{100}=20\right)$. With a resistance of five ohms, making the total resistance twenty-six ohms, there is utilizable as light the ten-thirteenth part of the current generated, or about 77 per cent. Applied to lamps of low resistance, as one ohm each, the arrangement would have to be materially changed; for, unless changed, the external resistance of the lamp circuit would be but one-tenth of an ohm $\left(\frac{10\times1}{100}=.1\right)$, and the total resistance of the system 6.1 ohms; whence it follows that we would only be able to utilize in the production of light 1.64 per cent. of the current generated.

Reversing this arrangement and providing 10 branches, each containing 100 lamps, we have a circuit resistance of 10 ohms $\left(\frac{100\times1}{10}=10\right)$; and with a generator resistance of 2.5 ohms, and a resistance in the mains of .25 ohm, mak-

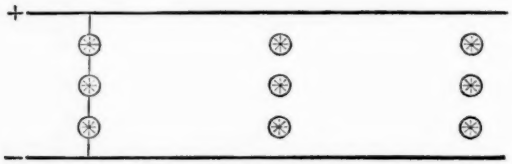


Fig. 69. Multiple-Series Circuit.

in the mains of one ohm, and in the gening the total resistance of 12.75 ohms, we are enabled to utilize as light 78 per cent. of the current generated; but we must light substantially the entire hundred lamps in each branch at once and extinguish them all at once, or else we must waste the current which would go to the lamps in equivalent artificial resistances when we extinguish a part of the lamps; for, as the current is to be equally divided among all the branches, a branch must in practice either be entirely cut off from, or its entire resistance interposed in, the circuit.

In the fourth or series-multiple system of subdivision (Fig. 70), as in the multiple-series system, the resistance of the external circuit may be anything desired, and there may be operated in the same circuit very many different combinations of lamps. The main conductor, which is single as in the series system, is cut at the points at which light is

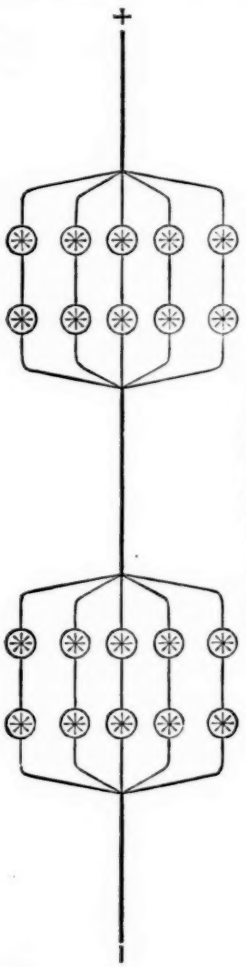


Fig. 70. Series-Multiple Circuit.

desired, and from the two disconnected ends a number of small conductors are run each to a lamp or series of lamps. In the operation of 1,000 lamps by this system there may be, say, one hundred points of divergence, and at each of these points ten lines of wire containing one lamp each. Thus the resistance of the lamp circuit is made 10 ohms $\left(\frac{100+1}{10}=10\right)$ and with a generator resistance of 2.5 ohms, and a resistance in the connecting conductors of .25 ohm, we utilize as light 78 per cent. of the whole current. With 10,000 lamps there may be 500 points of divergence, each containing 20 lamps, by which arrangement the resistance of the lamp circuit becomes 25 ohms $\left(\frac{500+1}{20}=25\right)$; and with a generator resistance of 5 ohms, and a resistance in the connecting conductors of 1 ohm, the proportion of current available for light is 80 per cent. of the total production.

We might continue these calculations indefinitely, but to no further purpose. The flexibility of the system is obviously such as to permit of any regular combination of lamps whatever, and thus to obtain any external resistance whatever; and it will be found to permit equally well of all irregular combinations, so that in one division, where the volume of light required is great, there may be, say, five lamps in multiple, and in the next division, where the volume of light required is ordinary, there may be ten lamps in multiple, each of the latter receiving but one-fourth as much current as each of the former, because the joint resistance of the ten lamps is .1 ohm, while the joint resistance of the five lamps is .2 ohm; and the ten lamps receive but half as much current as the five lamps, while the number of lamps is doubled. The closing-up, short-circuiting, or reducing the resistance of any division acts simply to reduce the resistance of the whole circuit, in the same manner as removing a portion of the lamps in a simple-series system. The relative advantages of the multiple-series and the series-multiple systems can only be determined by the number of lamps operated from a single source and the practical operation of both systems, although there are considerations of simplicity which would seem to favor the series-multiple arrangement of lamps, whose connection with a line of dwellings is illustrated in Fig. 71.

Regulators and Switches.—Although it is matter of common knowledge that a carbon loop or pencil, intensely heated by the passage of the electric current, becomes luminous, it is not generally known what proportion the degree of luminosity bears to the strength of the current. The precise relations of the current supplied and the light produced have never been determined; but results

which, it is believed, closely approximate the truth were first obtained in August, 1878.

A Sawyer-Man lamp of high resistance (.6 of an ohm) was employed in the tests then made; but it should be borne in mind that, without reference to the length or cross section of the carbon, so long as the current supplied is in proportion to its length and cross section, the percentages observed in one lamp are the percentages of all lamps in which wastage of the carbon by chemical action is obviated. Disintegration at the points of contact when these are imperfect, mechanical disengagement of particles of the carbon, and rupture due to imperfections in the constitution of

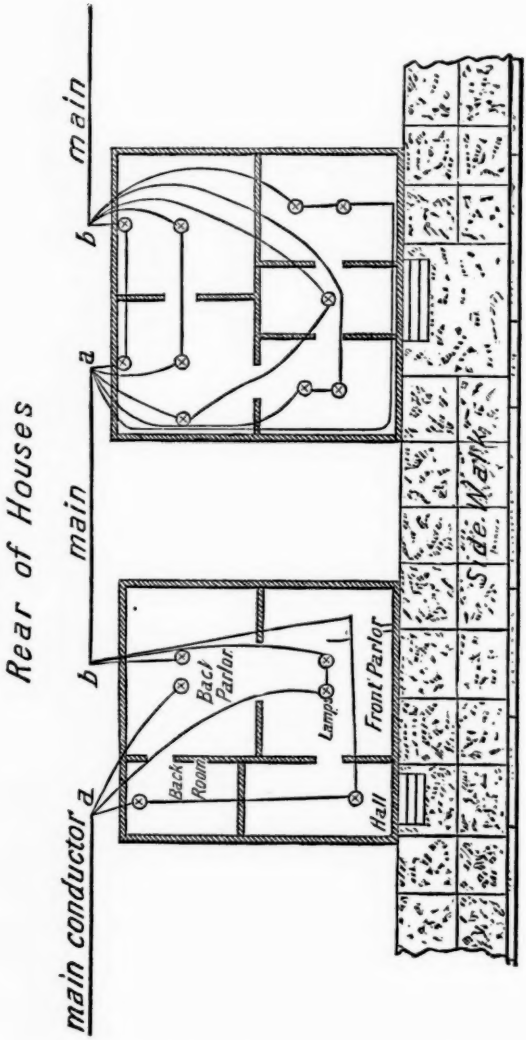


Fig. 71. House-Connections with Main Conductor. *a*, *b*, Points of Divergence.

the carbon are occurrences common to all incandescent lamps.

A dynamo-electric machine wound expressly for the purpose, and driven at an unvarying speed, was used; and as there was abundance of power, and as the speed remained constant under almost any circumstances, it was deemed necessary, in order to obtain a satisfactory result, that the resistance external to the machine should be kept constant. Therefore the internal resistance of the lamp to be experimented upon was measured, and it was found to be as stated. A new form of current regulator, afterwards known as the Sawyer-Man switch (Fig. 72), was employed in the tests.

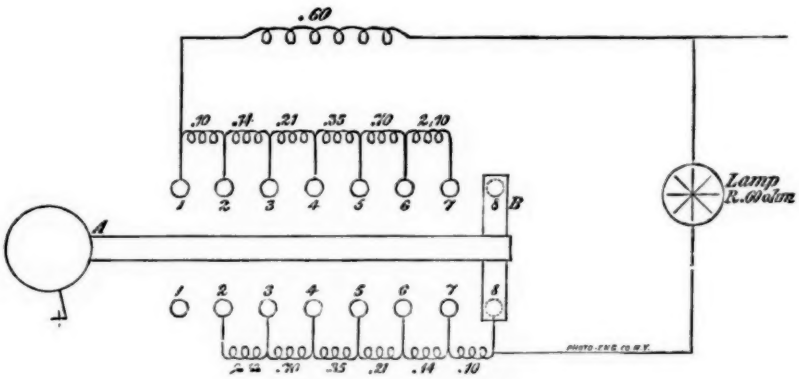


Fig. 72. The Sawyer-Man Switch.

The poles of the generator had connections at the + and − points, A being a sliding-bar, and the cross piece B being a spring contact-piece brought to a bearing upon the two rows of studs 1, 2, 3, 4, 5, 6, 7, 8, accordingly as it is moved backward or forward. Whatever position the cross piece assumes, it will be noted that the resistance of the circuit from the + to the − point is the same. In the position shown, all the current traverses the lamp. With the contact-piece B bearing upon the studs, 7, 7, two paths for the current are afforded, one by way of a resistance of .10 ohm and the lamp outward, making a total resistance of .70 ohm in that circuit, and the other by way of resistance of 2.10, .70, .35, 21, .14, .10, and .60 ohms, outward, the sum total of which series of resistances is 4.2 ohms, thus sending through the lamp six-sevenths of the current, while maintaining the resistance from the + to the − point the same.

It was found that when the volume of current supplied to the lamp was three-sevenths of the whole current, the contact-piece B bearing upon the studs 4, 4, the carbon was brought to a low red heat. With four-sevenths of the current supplied to the lamp, the carbon gave a light of about one candle; five-sevenths of the current, the light, measured by a Sugg photometer, was three candles; with six-sevenths of the current, nine candles; with the whole current, twenty-seven candles. When the contact piece B was bearing upon the studs 1, 1, the whole current passed through the artificial resistance of .60 ohm. The gradations of light by this means being too sudden (from less than one candle light to three candle light, from three to nine, and from nine to twenty-seven candle light), the resistances were subsequently changed so as to admit to the lamp first one-half of the current, then five-eighths, three quarters, seven-eighths, fifteen-sixteenths, thirty-one-thirty seconds, and finally the whole current. With this arrangement the gradations were gradual and pleasing.

The disparity between the volume of current supplied and the intensity of the light obtained is very clearly indicative of the requirements of an incandes-

cent lamp. Since five-sevenths of the total current for a single lamp produces but three candle-light, while the whole current produces twenty-seven candle-light, or nine times as much, it follows that in order to secure the maximum economy the carbon must be raised to a high temperature. For if we have a supply of current equal only to the maximum requirements of fifty lamps, from which we may obtain a sum total of 1,350 candles, we cannot divide this current among seventy lamps without sustaining enormous loss, as the sum total of light given by the seventy lamps will be but 210 candles, while the expenditure of power will be the same. There is a compensating influence in the case of lamps in series driven by a dynamo-generator, consisting in the increase percentage of current exterior to the generator when the resistance of the external circuit is increased.

To sustain the high temperatures necessary to the economical operation of an incandescent-lighting system the carbon must be hard, dense, and substantial; and in the absence of these qualities is found the explanation for the inefficiency of fine, filamentary carbons, which can never be safely brought above the temperature of a gas flame. Carbon incandescence (that of white light), unlike the incandescence of an iron or platinum conductor, is of two grades and various intensities. In the first the carbon is intensely white, and its form optically broadened and lost in a surrounding haze of light. In the second and more intense incandescence its form stands out sharply defined, and it appears no longer opaque but limpid, seemingly translucent, like the body of the sun. It is to this degree of intensity that economical lighting by incandescence is confined.

The Sawyer-Man switch affords a ready means of dividing the current in any desired manner, while maintaining the resistance of a circuit constant. Thus any number of lamps provided with it may be operated by a single generator, and any portion of them may be regulated to any desired degree of intensity without affecting other lamps in circuit. The objection to its use consists in the fact that when a lamp is extinguished the work of the generator is not lessened, but the entire current that served to operate the lamp is wasted in heating an artifical resistance. It was this consideration that led to the designing of the graduating switch (Fig. 73),

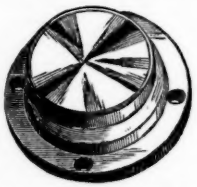


Fig. 73. Small Sawyer Switch.

which is fixed to the wall of a room or in any other convenient place, or attached to the lamp fixture. In this switch, which is illustrated apart in Fig. 74, there is an insulating disc, upon

Fig. 74. Switch apart.

which are fixed four brass segments, of a circle. Over this disc is placed the brass enclosing cap, through which passes loosely a slotted iron pin carrying a brass contact bar, which is forced to a bearing upon the brass segments, by means of a steel spring coiled in the head of the cap. Upon the end of the iron pin the finger piece is finally screwed. By turning the finger piece in one direction or the other the light is turned on or off, or regulated to intermediate points of intensity. In Fig. 75 the switch, as attached to the arm of a chandelier or bracket, is illustrated, the circular case at the end of the arm being shown partly in section. The lamp is fixed to the nipple above the switch case, and the insulated conducting wires pass through the hollow arm. The connections of the switch are shown in Fig. 76.

When both ends of the cross bar A are bearing upon segment 4, the whole current passes through the lamp. When the cross bar bears upon segments 3 and 4, the current divides, a part passing through the lamp and part through the artificial resistance of .50 and .25 ohm. When the cross bar bears upon segments 2 and 4, the current is divided between the lamp and the artificial resistance of .25 ohm. Bearing upon segments 1 and 4, the lamp is short-circuited and practically receives no current. The artificial resistances are preferably made of naked copper wire exposed to the air or embedded in plaster-of-Paris and enclosed in the case (Fig. 75).

By means of this switch it is clear that when a lamp is extinguished its resistance is removed from the circuit, and the current is not wasted in heating an artificial resistance. But in order that changes which take place in its circuit may not add to or lessen the volume of current supplied to other lamps, it is necessary that the changes which occur in its circuit shall in some manner react upon the source of the current; and this brings us to the consideration of

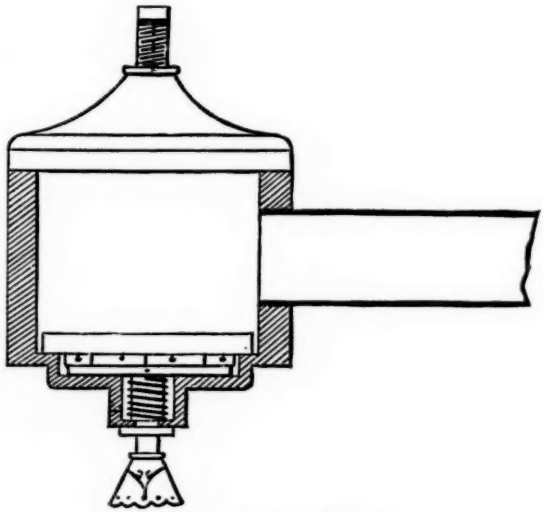


Fig. 75. Switch attached to Bracket.

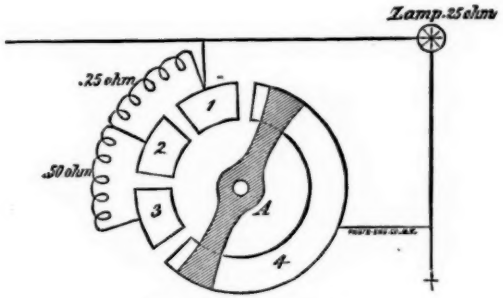


Fig. 76. Switch Connections.

regulators operating to supply current in proportion to the requirements of a system.

Before taking up this subject, however, a form of switch designed for use upon a circuit of lamps in series, where

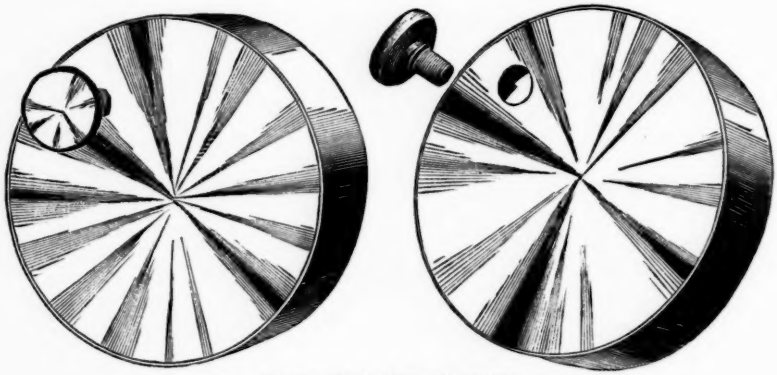


Fig. 77. Electro-Magnetic Switch.

interruption of the circuit at any one lamp would, without it, result in extinguishing all the lamps in circuit, will be described.

In Fig. 77 the switch is shown as fixed to the wall of the room, and also with its cover and finger piece apart. In Fig. 78 the interior mechanism is

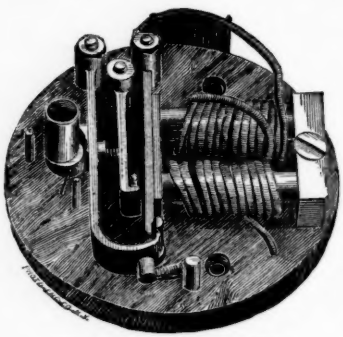


Fig. 78. Mechanism of Switch.

illustrated. In Fig. 79 we have a diagram of the connections.

A is the magnet-lever; B and C are other levers; D is a cam operating to raise and lower lever C, which is pressed downward by coiled spring H. Lever B is pressed upward by insulated spring E. F and G are stop-pins, and I is an artificial resistance.

In the position shown lever A is in contact with stop-pin G. Lever B is in contact with stop-pin F, but not with lever A. Lever C is in contact with cam D, but not with lever A. The current, therefore, passes from the + point through the coils of the magnet to the lamp and outward at the − point, the armature lever being attracted to its contact with stop-pin G and the entire current passing through the lamp. To extinguish the light cam D is moved a little to the right, but not leaving its contact with lever C, when lever C is pressed downward to a contact with lever A. The lamp is thus short-circuited, the current passing from the + point through levers A and C to the cam D and outward at the − point. To give the lamp sufficient current to produce one-half its full light, the cam D is moved further to the right, so as to pass from its contact with lever C. Then lever C, falling further, forces lever A to make connection with lever B, and the current divides, a part flowing from the + point through the coils of the magnet and the lamp outward, and the remainder flowing, by way of levers A and B and resistance I, outward to the − point. With the cam turned to the intermediate point the lamp is extinguished. Turned as far as it will go to the right, one-half of the light is emitted. Turned as far as it will go to the left, the maximum in-

tensity of light is produced. In the event of an interruption of the lamp circuit the lever A, which, when the circuit is complete, is attracted by the magnet, drops to contact with lever B, and the circuit is re-established by way of resistance I. Lever A can only be drawn towards the magnet when the pressure of spring H is removed by raising lever C from its contact with lever A.

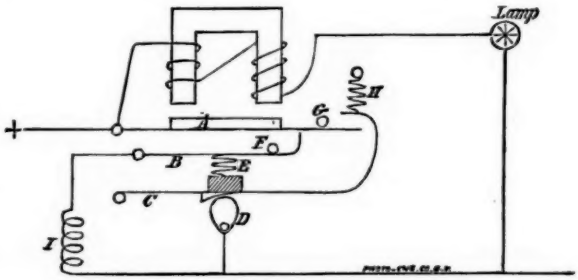


Fig. 79. Electro-Magnetic Switch Connections.

A form of artificial resistance useful in electric lighting is illustrated in Fig. 80, in which a rod of carbon is held in brass connecting clamps upon a soapstone base. A thin piece of platinum, to establish perfect contact, is placed between the end of the carbon and a plate of brass upon which the upper set screw presses. Copper wire for artificial resistances is preferable to iron wire of equal diameter, owing to the greater surface exposed to radiation and convection of heat by the better conductor; and copper ribbon, for the same reason, is preferable to either.

Fig. 80. Carbon Resistance.

In the Edison and Maxim systems of lighting the ordinary make-and-break circuit switch is employed. In respect to simplicity it cannot be improved, but it affords no means of graduating the light, which must either be kept at its full power or entirely extinguished. The Edison switch, however, like the switches employed in the Sawyer system, does not interpose current-wasting resistances when no light is required, the supply of electricity being supposed to be regulated at the generator in proportion to the requirements of the circuit.

Many attempts at automatic regulation of the supply of current have been made both in this country and abroad, the nearest approach to its realization by foreign electricians being the device of Dr. Siemens, who in January, 1879, proposed to place a number of carbon discs in an insulating tube, pass the current through them, and by means of a platinum wire, also in the circuit, to vary the conductivity of the carbon pile by varying the pressure of the discs upon each other. For several reasons, unnecessary to state, this arrangement could have no practical application in an electric-lighting system.

The conditions to be met are not so easily met as might appear from a superficial examination. Let us suppose that there are ten lamps, of one ohm resistance each, arranged in multiple-circuit, and that each lamp receives one-tenth part of the whole current. Suppose, now, that we add a lamp; then each lamp receives but one-eleventh of the former current. We must, therefore, so increase the supply that each of the eleven lamps shall receive as much current as each of the ten lamps received before. To accomplish this increase, there are two very similar forms of regulators, the first of which was patented by Sawyer & Man, June 25, 1878, and the second of which was recently devised by

Mr. Maxim. The latter is illustrated in Fig. 81. Its operation is as follows: In one of the branches across the two main conductors of a multiple-circuit system is placed the electro-magnet A. A proportion of the current, dependent upon the difference in the resistance of the magnet branch and that of all the multiple-lamp branches, traverses the magnetic coil; and as this proportion varies according to the number of lamps in a circuit, it is obvious that the force with which its armature is attracted varies. When the supply of current is insufficient the armature is released, and by means of a system of gear wheels, operation are such as to cause a rhythmical increase and decrease of the intensity of light from the lamps connected with it, owing to the failure of the armature mechanism to act until the strength of the current has too far exceeded or fallen too far below the point at which it must remain in order to produce no appreciable alteration in the intensity of the light. The interposition of a sensitive relay, operating to open and close the circuit of the magnet A, instead of placing the magnet A in the main circuit, would have operated to maintain the intensity of the light constant.*

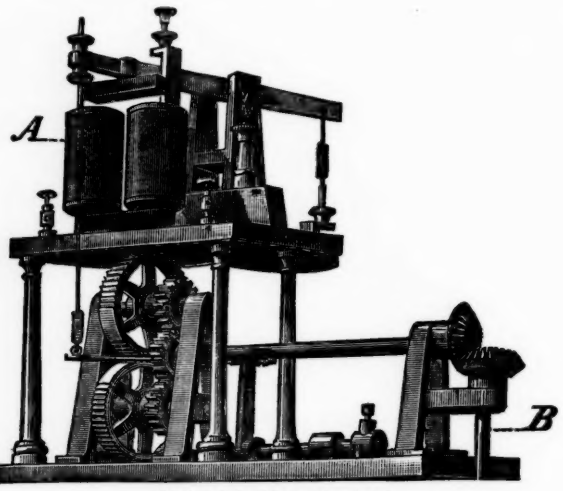


Fig. 81. The Maxim Regulator.

continuously in motion, the shaft B is rotated in one direction, and the commutator brushes of the generator are thereby so set as to supply a greater volume of current. When, on the other hand, the supply of current becomes too great, by reason of the removal of lamps from the circuit, the armature is attracted, and through the system of gear wheels mentioned the shaft B is rotated in the opposite direction, and the commutator brushes are thereby so set as to yield a less volume of current. These are the principles of this regulator, which it is only reasonable to suppose is as yet undeveloped. The considerable changes in current force necessary to its

In the Sawyer system of regulating the supply of current, without regard to the speed of the generator or the electromotive force of the current (Fig. 82), we have first to find the proper relation between the strength of current and the number of lamps to be operated. Let us suppose that there are ten lamps arranged in series, and that the full cur-

* In Letters Patent of the United States, No. 223,659, of January 20, 1880, granted to Professors Thomson and Houston, members of the Franklin Institute of Philadelphia, the principles of this regulator are described, with the following claim:

"As a motor for effecting the adjustment of the commutator-collecting brushes, an electro-magnet, M, traversed by the current, or a portion of the current, of the machine, whose attraction upon its armature, N, moves said commutator-collecting brushes in one direction, motion in the other direction being obtained by the action of a spring."

rent is exactly sufficient to operate these lamps at their maximum intensity. At any point in the circuit we place an electro-magnet, B, having the sensitiveness of a telegraphic relay. The relation of this magnet towards the regulating apparatus is actually the same as the relation of the telegraphic relay towards the local telegraphic instrument. The armature lever of this magnet is set between two contact points, between which it plays without appreciable motion. Indeed, both points may be in actual contact with the lever, so that the latter shall not move at all; but the local circuit shall be changed by the change in resistance due to the mere difference in pressure of the relay-lever upon the separate contact points. Thus resistance of the lamp circuit is reduced to 1.25 ohms, and the effect of the current upon B is correspondingly increased. Its lever at once actuates the regulating mechanism, which moves lever A to contact with stud 6, thus bringing the resistance of the circuit to its normal point, viz., 2.5 ohms. The same action ensues whenever a lamp is short-circuited, and the reverse action whenever an additional lamp is thrown into the circuit. In practice the resistances D D are greater in number and each of a less value than described, but the sum total of all remains the same. The lever of B in practice is in constant vibration between its contact points, and the lever A is in constant vibration between two contiguous studs or segments of the

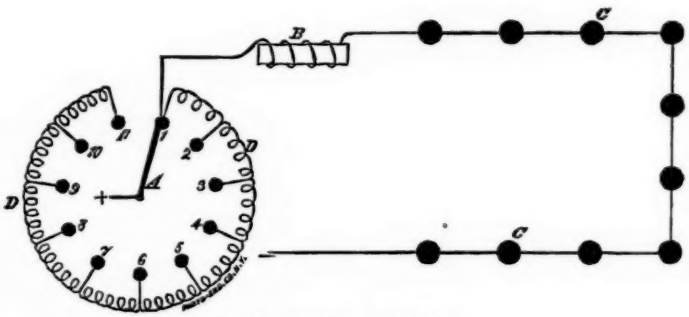


Fig. 82. System of Regulation.

arranged, variations in the strength of the lighting current, sensible only to a galvanometer, may be made to operate the circuit of a local battery, and thus to energize electro-magnetic regulating mechanism.

Let CC be the ten lamps in circuit, and A a rotating contact lever. DD represent a series of ten artificial resistances, the sum total of which is 2.5 ohms. The sum total of the resistance of the ten lamps in circuit is also 2.5 ohms. When all the lamps are in operation, the circuit pases from the + point to the stud No. 1, and thence through relay B and the ten lamps CC to the — point. The resistance of B is for convenience disregarded, as it is but a fraction of the total resistance. Suppose, now, that we extinguish half of the lamps by short-circuiting them. The circle, in addition to its positive movements over a greater or less number of studs.

In the engraving (Fig. 83), from a photograph, is illustrated the Sawyer electro-magnetic regulator. The large gear wheel, whose shaft carries a rotating contact arm, corresponding to lever A of Fig. 82, making connection seriatim with a number of insulated segments of a circle enclosed in an oval-top case, is set in motion by a pinion on the shaft of a small reversing electric engine enclosed in the central round metal case. When there is too great a supply of current, the armature lever of the magnet in the main circuit establishes the local circuit of a commutator which drives the engine in one direction; when there is too little current, the armature lever establishes the circuit of a second commutator which

drives the engine in the opposite direction. In the first instance resistance is introduced in the main circuit. In the second instance resistance is removed from the circuit.

Imperfections due to the oxidization of contact points in the electric engine, and the occasional failure of the engine to respond to changes in its circuit, led to the abandonment of what was otherwise a successful regulator, and the substitution therefor of hydraulic-cylinder and piston mechanism, constituting the regulator shown in Fig. 84, which is also from a photograph.

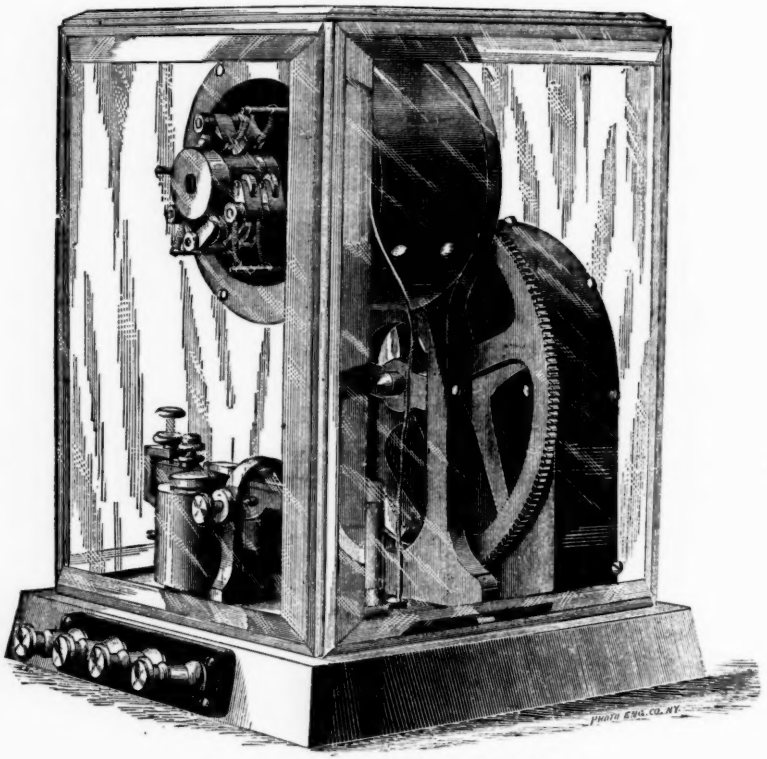


Fig. 83. The Sawyer Electro-Magnetic Regulator.

The internal arrangements of the regulator are shown in Fig. 85, in which J is a hollow metal base containing the various resistances connected with the 18 pieces F, corresponding to the 10 studs or segments of Fig. 82. B is a cylinder fixed to the base J and open at the top. Closely fitting in cylinder B is the cylinder A, open at the bottom. Supported by a tube passing through the base, and closely fitted in cylinder A, is the piston C. Insulated upon one side of cylinder B is a stationary contact plate E, to which one pole of the generator is attached. Insulated upon the opposite side of the cylinder are the 18 grooved central plates F. Running in the grooves of E and F are two contact arms, G and H, whose pressure upon E and F is regulated by spring I. The current, therefore, passes by way of plate E to arms H and G and a contact plate F outwardly, as shown in the regulator connections, Fig. 82. The ends of the cores of an electro magnet, K, provided

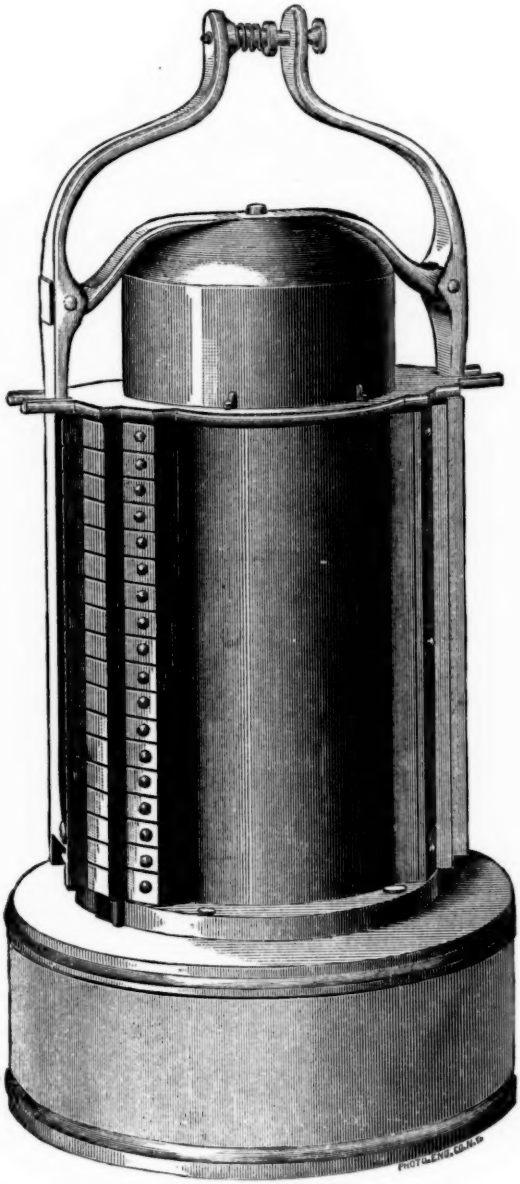


Fig. 84. Hydraulic Regulator.

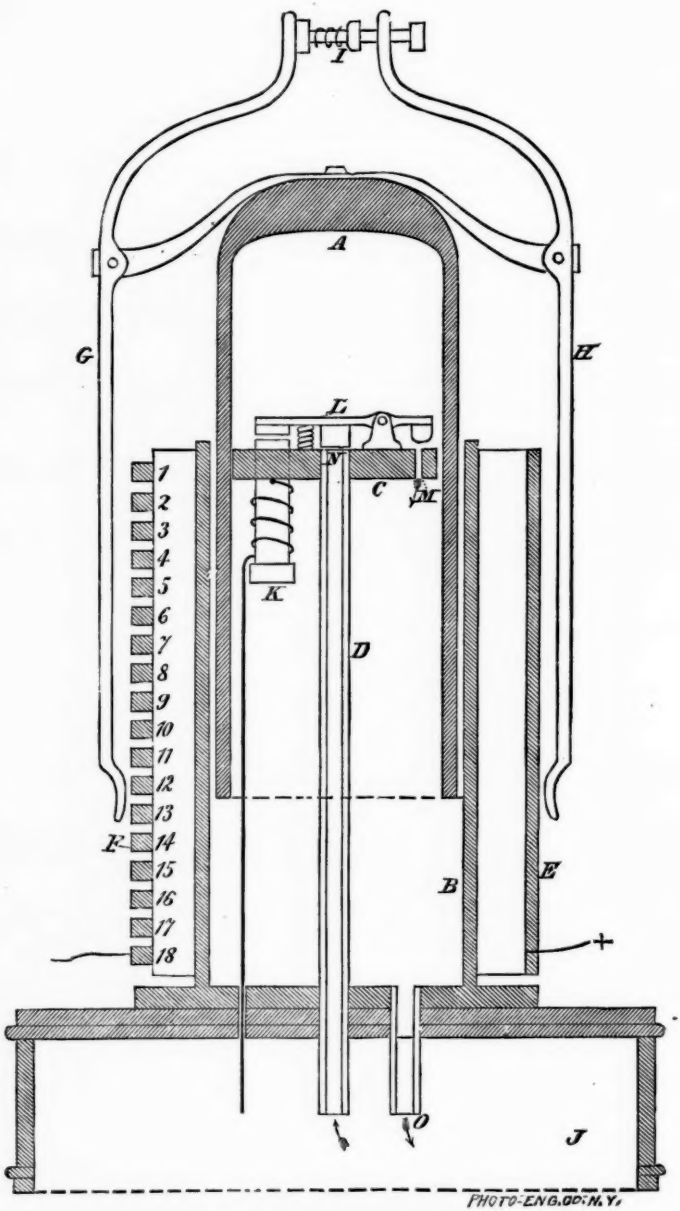


Fig. 85. Hydraulic Regulator Mechanism.

with an armature lever, L, pass through the piston head, and serve to open and close the valves NM. When the magnet K is not energized, a coiled spring forces the armature away, and valve N is opened to the flow of a stream of water, and valve M is closed against its escape into the lower chamber and outwardly through the exit tube O. Therefore the cylinder A rises. When the magnet is energized, the valve N is closed and the ingress of water stopped, while valve M is opened and the water contained in the upper chamber is allowed to escape. The cylinder A then falls by its own weight as rapidly as the escaping water permits. By a suitable arrangement the waste water is used to cool the various artificial resistances. The local circuit of the magnet K is established by the back contact of the relay lever. The movements of the cylinder A are smooth and the changes rapid. The contacts of G and H with F and E are of a firm and substantial character. With a pressure of 10 pounds of water and a piston area of 10 square inches, the cylinder A is raised above its weight with a force of 50 pounds; and as its weight is 50 pounds, it obviously falls with the same force. With a piston area of 80 square inches and 20 pounds pressure of water, a circuit is operated, with singularly rapid changes in the direction of movement of the cylinder, with an upward force in the cylinder of 1,600 pounds. There is apparently no limit to the powerful effects thus producible by minute changes in the strength of current supplied to a system of lamps. By means of these regulators, the changes in the circuit occasioned by the Sawyer switches for graduating the light are instantly balanced; but the fact remains that as much power is expended in driving the generator when there are a few as when there are many lamps in circuit, and in a general distributing system, where economy is the prime consideration, such regulators, however perfect in their operation, can have no practical application."

Quite as valuable as the above is the author's presentation of the subjects of "General Distribution" and "The Commercial Aspects." But for these topics we must refer the reader to the book itself.

STREET CARRIAGEWAY PAVEMENTS.

By GEORGE FREDERICK DEACON, M. Inst. C. E.

From Proceedings of the Institution of Civil Engineers.

As a branch of civil engineering street paving has never occupied a very high place. It is true that, when once the conditions of its maximum economy and efficiency are ascertained, exceptional skill is not required to put them into practice; but those conditions have rarely received at the hands of engineers the consideration in detail which they demand; and when the very high degree is duly appreciated, in which the welfare of the community is influenced by the method of paving adopted, it must be conceded that the divergent opinions and practice at present extant should at once be formulated and fairly compared. The proceedings of the institution have contained no discussion on the subject for many years. The author therefore proposes to state his practice, and to tabulate its results in a manner which, if generally adopted, will remove much of the present difficulty of making accurate comparisons between the various classes of pavements and the different modes of constructing them.

The present paper will be confined to street carriageways, and will exclude the consideration of such roads as form lines of communication between centers of population, or between scattered rural dwellings and market towns, railway termini, or harbors. The former division of the subject of road making offers abundant matter for consideration in a single paper, and the latter division has been ably dealt with by Mr. W. H. Wheeler, M. Inst. C. E. The details and cost of construction of certain pavements will be given, and their relative ad-

vantages will then be generally considered.

I. CONSTRUCTION. — CARRIAGEWAYS OF HAMMER-DRESSED STONE, OR SET PAVEMENTS.

Figure of Sets.—Sets when properly secured in position and formed of the hardest stones are so durable, even under the heaviest traffic, that it is not worth while to make them more than from 6 to 7½ inches deep. Two depths are employed in Liverpool: the first for moderate traffic, averaging 6¼ inches; and the second for the heaviest traffic, averaging 7¼ inches. In relation to its other dimensions, a set should be of such depth that when the wheel of a heavy cart passes over one edge of its upper surface it should not tend to tip. The resultant direction of pressure of the load and adjoining sets should, in short, always tend to depress the whole set vertically. Where, as frequently happens, this precaution is neglected, the maintenance of a uniform surface is impossible. This consideration would lead *per se*, for sets of the above-mentioned depth, to a surface of 4 or 5 inches square. Sets of this figure remain comparatively stable, even on bad foundations and with defective joints. There are other influences, however, which lead to a modification of this form. It is desirable that the width of each set measured along the street should be small. If it is large, a horse drawing a heavy load attempting to find a joint slips back, and requires an exceptionally wide joint to pull him up. The wide joint induces increased wear of the upper corners of the sets, and increased noise.

In practice, the author has found that, for all but the softer stones, upon which, even if there were no joints, horses could travel with facility, it is desirable that the widths of the sets should be such that four taken at random, and placed side by side, will not measure more than 14 inches across. As in this measurement the irregular projections of the sets are taken into account, the average surface width is less than 3 inches; and if with this width the surfaces are square, the number of longitudinal joints is so great that it is impossible for the paviors to break joint properly, and at the same time to keep the joints close, without much loss of time in selecting each set as it is placed. Two or more longitudinal joints in nearly the same line, or a single rather wide longitudinal joint, almost invariably initiates a groove.

The square form which, for stability, would otherwise have been the best, has therefore been altered in the author's practice to an oblong of the width above stated, and of a length varying from 5 to 7 inches, which, when the set is fixed in position in the manner about to be described, is not found to be too great in relation to the depth to secure stability.

These conclusions may be summarized as follows:

HARD STONE, IN WHICH JOINTS ARE NECESSARY FOR FOOTHOLD.

	Depth. in.	Width. sets. in.	Length. in. in.
Sets for moderate traffic....	6 to 6½	4 to 14	5 to 7
Sets for heaviest traffic....	7 " 7½	4 to 14	5 " 7

SOFTER STONES, IN WHICH JOINTS ARE UNNECESSARY FOR FOOTHOLD.

	Depth. in.	Width. sets. in.	Length. in. in.
Sets for light traffic or inclines.....	6 to 6½	3 to 14	5 to 7

Materials of Sets.—Among the igneous, plutonic, and metamorphic rocks are to be found a great variety of stones suitable for paving, of all degrees of hardness, brittleness, and toughness; but the durability under traffic, the tendency to wear round rather than flat and to become slippery, are dependent upon no conditions which can readily be foreseen. The size and distribution of the crystals, the nature and hardness of the constituent minerals, operate in such a manner that two opposite combinations often produce nearly the same result; while rocks of nearly equal hardness frequently behave very differently under traffic. The specific gravity, moreover, appears to afford no assistance in the determination.

The only sedimentary rocks which it is desirable to use for street pavements are some portions of the millstone grits and other more laminated grits of the coal measures, and the use of these should be confined to steep gradients and to streets of little traffic. Specimens of rocks used

in Liverpool for paving are exhibited, and in the following table (page 240) are stated the localities from which they are obtained, their lithological characters, and their behavior under traffic, so far as is known to the author, when paved as described in this paper.

Mode of Jointing.—Until 1871 the joints of Liverpool set pavements were simply filled with gravel, well worked down with a tool called a cramming iron. In many towns a grouting of hydraulic lime and gravel is brushed into the joints. The first method answers moderately well for streets of light traffic; the second binds the gravel to some extent, but in very few cases do the sets fail to work loose, and the grouting to become disintegrated, even if the vibration of the traffic, which is generally too soon turned upon the pavement, has ever allowed it to set firmly. Joints made according to the first method are always very pervious to water; those made by the second method are less so; but, owing to the fact that the grouting is almost always disintegrated, they are far from impervious.

In pavements of which the foundations are not of concrete, imperviousness is of the utmost importance; for where water can percolate to the substratum, that substratum is softened, and under continuous traffic portions of it work up through the joints, or press the sets upwards in places where the traffic is lighter. In either case hollows are formed. Unless a strong concrete foundation is employed, it is useless to attempt to make the joints impervious with a brittle material such as cement or lime; and so far as the author is aware, the only thoroughly impervious joints under such circumstances have been formed with various asphaltic compositions. For more than thirty years the authorities of many towns in Lancashire and Yorkshire have made the joints of their pavements by first filling them with clean gravel, and then pouring in a boiling asphalt of pitch and creosote oil.

A crucial examination of many classes of pavements satisfied the Author, in 1871, that those jointed with asphalt retained their figures better, and wore out less rapidly, than any others. This method of jointing is often very indifferently performed; and, as it is scarcely known in the South of England, it may be useful to describe in detail the mode which experience has shown to be the best. The sets, which should be dry, are paved as closely as possible, having regard to the maintenance of each course in a straight line, upon whatever foundation may have been prepared for them. If upon a concrete foundation, about $\frac{3}{4}$ inch of sharp sand is allowed to intervene between the pavement and the foundation.

When a considerable area is ready, it is covered with clean, dry, and hard gravel, which has been passed through a $\frac{3}{4}$-inch riddle, and rejected by a $\frac{1}{4}$-inch riddle. When this gravel has been well brushed into the joints, the sets are thoroughly rammed with the old-fashioned two-handled vertical rammer, which the rammerman swings between his legs. The effect of this is to shake the gravel down, and cause it in most places to disappear; more gravel is then added, and the ramming repeated. After a third, if not after the second, gravelling and ramming, each set should be perfectly firm. The vibration of the ramming shakes the pebbles even into the narrowest spaces, where they act as most efficient wedges. The firmness of the pavement even at this stage is generally surprising to those who see it for the first time.

The asphalt is prepared in boilers on wheels. The large-sized boilers for making carriageways contain about 25 cwt. of asphalt, while the small sizes used for repairs contain from 5 to 10 cwt. The coal-tar pitch employed costs in Liverpool about 1s. 6d. per cwt. Care must be taken that it is not too brittle; foremen accustomed to the work can judge of this quality by biting it. Pitch, from which so much of the essential oil has been expelled as to make it brittle, and to raise its melting point too high, will never assume that permanently plastic condition, when boiled with oil, which is necessary to prevent subsequent cracking. The oil employed for softening the pitch is the impure carbolic acid or dead oil from the distillation of coal tar. It is known in the trade as creosote, or creosote oil, but is quite distinct from true creosote. It costs about 2½d. per gallon. About fifty gallons of creosote oil are required for every ton of pitch, but the

Locality from which sets are obtained.	Description of stone.*	Specific gravity.	Behavior under traffic.
A. Penmaenmawr, Carnarvonshire (old quarry): sets from this quarry have not been laid in Liverpool since 1871.....	Very close-grained. (*Quartz, felspar, hornblende*)	2.75	More durable than any rock known to the author, but becomes very slippery under traffic. Corners apt to wear round by chipping off.
B. Penmaenmawr, sets now used.....	Close-grained. (*Quartz, felspar, hornblende*)	2.82	Very durable; suitable for the heaviest traffic in streets of moderate gradients. Corners apt to wear round by chipping off.
C. Port Nant, Carnarvonshire..	Close-grained. (*Quartz, felspar, hornblende*)	2.70	Very durable; nearly as hard, and not so slippery, as B.
D. Yr Eifl, Llanaelliaiarn, Carnarvonshire.....	Close-grained. (*Quartz, felspar, hornblende*)	2.63	A very tough rock, nearly as hard, and not so slippery, as B. Corners not so apt to wear round. Suitable for the heaviest traffic in streets of moderate gradient.
E. Pistyll, Carnarvonshire.....	Close-grained. (*Quartz, felspar, hornblende*)	2.60	Wears similar to C.
F. Llanbedrog, Carnarvonshire.	Coarse-grained. (*Felspar, quartz, hornblende*)	2.53	Has not been long used in Liverpool. It is not slippery, and is moderately durable.
G. Festiniog, Carnarvonshire...	Rather coarse-grained. (*Felspar, quartz, hornblende*)	2.59	Has not been long used in Liverpool. It is not slippery, and appears to be as nearly as durable as F.
H. Minnford, Portmadoc, Carnarvonshire.....	Close-grained. (*Quartz, felspar, hornblende*)	2.9	Free from slipperiness: harder than J, but in other respects similar.
J. Gimblet, Pwllheli, Carnarvonshire.....	Rather coarse-grained. (*Hornblende, felspar, quartz.*)	2.9	Not so hard as H; free from slipperiness, and wears to a very flat surface.
K. Newry, Ireland.....	Coarse-grained. (*Felspar, quartz, hornblende*)	2.7	These are softer rocks than any of the foregoing; but where the cost is small, they are satisfactory for inclines, or streets of light traffic. They are not slippery.
L. Bessbrook, Ireland.....	Coarse-grained. (*Felspar, quartz, hornblende*)	2.65	
M. Dalbeatie, Scotland.....	Very coarse-grained. (*Quartz, felspar, horndlende*)	2.7	Softer than K and L: not slippery.
N. Bagbie, Creetown, Scotland..	Coarse-grained. (*Quartz, felspar, hornblende*)	2.62	
O. Lancashire.....	Millstone grit.....	2.44	Only suitable for the lightest traffic. May be employed with advantage in streets of very steep gradient.

*The author is indebted to Mr. Isaac Roberts, F.G.S., for the determination of the order of the relative volumes of the constituent minerals, in which order they are placed in the second column of the table.

exact quantity depends chiefly upon the quality of the pitch. During the process of boiling, the consistency of the asphalt is determined from time to time by cooling small portions in water and kneading it in the fingers.

The hot asphalt is drawn off into iron buckets, each containing rather less than 1 cwt. Each bucket is carried to the prepared pavement on a carrying bar between two men, and the contents ladled out. No attempt is made to run it into the joints without covering the whole surface. The asphalt penetrates the smallest interstices, and for many hours after the joints are apparently full it continues to sink until only a thin coating is left on the surface, with here and there a hole, which is filled from a small ladle. Lastly, the pavement is finished by covering it with small sharp gravel, which, with much of the remaining pitch, is subsequently squeezed into the joints by the traffic.

The cost per square yard in Liverpool, of pavements laid as above described, exclusive of the foundation and of excavation, is as follows :

IMPERVIOUS PAVEMENT WITH ASPHALT JOINTS, AS NOW LAID IN LIVERPOOL.	s.	d.
0.31 ton Stone sets 7¼ inches deep, including cartage, at 28s.....	8	8
0.064 ton Gravel for bedding, ¾ inch thick, cartage at 6s. 6d.....	0	5
0.015 ton Pitch, cartage at 30s.....	0	5.25
0.6 gallon Oil, cartage at 2½d.....	0	1.5
0.002 ton Coke, cartage, at 12s.....	0	0.25
0.018 ton Shingle, dried and riddled, at 7s.....	0	1.5
Labor.....	0	8.5
	10	6
Add establishment expenses, 8 per cent.....	0	10
Total per square yard.	11	4
Similar pavement with sets 6¼ inches deep per square yard.....	10	4

Pervious pavements with ordinary gravel joints as formerly laid in Liverpool (present prices per square yard):

	s.	d.
0.31 ton stone sets, 7¼ inches deep, including cartage, at 28s.....	8	8
0.096 ton gravel for bedding, 1 inch thick, including cartage at 6s. 6d.	0	7.5
0.02 ton gravel for joints, 1 inch thick including cartage, at 6s..... ..	0	1.5
Labor.....	0	5
	9	10
Add establishment expenses, 8 per cent.	0	9
Total per square yard.....10	7	

	s.	d.
Similar pavements with sets 6¼ inches deep per square yard....	9	6

FOUNDATION.

It has already been stated that in 1871 the author gave the preference to asphalt-jointed pavements. Prior to that time they had never been employed in Liverpool; and as the Liverpool traffic was probably heavier than that of any other town, it became necessary to consider whether, in addition to the change in the method of jointing, any alteration should be made in the foundations of the carriageways.

In the oldest Liverpool streets the sets had simply been paved upon an old macadamized surface, but in those more recently constructed, it had been usual to form foundations after the manner adopted by Telford for highways, of which the wearing material was broken stone. Those foundations consisted of rough stones, 10 or 12 inches long, set on end by hand to the proper curvature of the road. The tops of any projecting stones were broken off, and the hollows filled in with smaller stones and rolled. The traffic was then allowed to pass for several weeks before the pavement was laid.

	s.	d.
Present cost per yard of hand-pitched foundation, as formerly adopted in Liverpool	1	5
Add for establishment expenses, 8 per cent.....	0	1.36
Total per square yard.....	1	6.36

Apart from all other considerations, this method of forming the foundation was obviously undesirable, where it was necessary to reconstruct the pavements of existing streets, on account of the long time occupied in consolidation.

In Manchester, where the pavements were, on the whole, the most perfect the author had seen in any of the towns examined, the sets were simply laid upon a well-consolidated bed covered with cinders, and the impervious joints were trusted to prevent the unequal sinking so generally caused by water soaking into the foundations; but where heavy traffic constantly passed over the same lines, the sets did undoubtedly sink beneath those lines. The author decided, therefore, that, for the heavier traffic at least, it was desirable to employ con-

crete foundations. Subsequently asphalt-jointed pavements were tried, both with and without concrete foundations, with so marked an advantage in favor of the concrete that it has since been used in all except the quietest streets, and within the last six years about 200,000 superficial yards have been laid. The methods adopted have varied slightly from time to time, but experience has led for some years past to the following practice: The concrete employed is either Portland cement or bituminous concrete. Before reconstructing a carriageway for heavy traffic, parts of the existing foundation are exposed in many different places. If, as often happens, no part of this foundation is worth retaining, the ground is excavated to the proper depth for Portland cement concrete. If, as sometimes happens, either an old macadamized road, or an old hand-pitched foundation, is met with at a sufficient depth below the base of the proposed pavement, Portland cement concrete is still employed. If, on the other hand, the macadamized surface or the hand-pitching reaches in places close up to the pavement, so that only a very thin stratum of concrete can be used without removing it, bituminous concrete, incapable of cracking, is used in preference to the comparatively brittle Portland cement concrete.

Portland Cement Concrete Foundations.—Where, as in the case of a carriageway foundation, a comparatively thin stratum of concrete is required, it is especially necessary that that stratum should be uniform in strength, or homogeneous, if the term can be properly applied to such a mixture. The most perfect concrete which the author has produced is made as follows:

The ground on which the foundation is to be laid is first well watered; upon it is then scattered a layer of wet broken stone like coarse macadam; upon this layer is spread with the spade a thin stratum of cement mortar, and upon the mortar a further layer of wet broken stones. The upper layer of broken stones is then beaten into the lower layer with beaters like large spades, with straight handles 4 feet 4½ inches long and flat beaters of sheet iron about 12 inches square and ¼ inch thick. Another stratum of mortar, followed by a third of stone, is then laid, and the beating process continued; and so on, until the required thickness is attained, when the surface is first beaten and then finished by rubbing with the beaters to the proper curvature of the carriageway. The surface is thus made as smooth and uniform as a plastered wall. By this method a complete but thin coating of mortar is left round every stone, and a maximum of strength is attained with a minimum of cement. When cut through, no sign of lamination is found. The mortar is composed of six parts by measure of gravel and one of Portland cement. The broken stones, measured separately, represent about eight parts, but when the whole is mixed and beaten together, the proportion of stones and gravel to set cement, is as 11 to 1. This, however, includes the upper layer, in which there is more than the average proportion of mortar.

No cement is allowed to be used, the tensile strength of which is less than 800 lbs. on a section of 2¼ square inches, or which sets in less than three hours so firmly as to take no impression from a Vicat's needle, having an area of $\frac{1}{400}$th part of a square inch and a weight of 2½ lbs., or of which more than 10 per cent. is rejected by a 50-gauge sieve. Though seldom laid more than 6 inches in thickness, this concrete is so strong that when, for the purpose of laying new service pipes, or of reaching old ones, it has to be removed, it is simply cut with a saw-pick, just as slabs of stone are quarried, in pieces about three feet square. When the excavation has been refilled and rammed, these blocks are relaid, cemented to the old concrete, and paved upon at once. On the following day the traffic is allowed to pass over them, and no subsequnnt sinking has ever been known to take place—a striking contrast to the old system, in which the paving over trenches in streets of considerable traffic was generally relaid three times, and sometimes oftener.

The author desires to lay great stress upon the homogeneity and strength of the concrete, which renders it possible to saw it out, and upon the smoothness and exact form of the surface, which not only insures uniformity of the subsequent paving, but guides the workmen in replacing cut-out blocks.

Experience has shown that concrete, made in the manner described, should not be paved upon for at least eight days after being placed *in situ*. Eight days is a serious addition to the time during which part of a street must be closed for pavement, but in order to obtain the best result the inconvenience must be endured; moreover no real advantage is gained by paving one-half at a time, and leaving less than one-half open to traffic. It is impossible under such circumstances to do the work so well; it is impossible to do it so quickly; and the blocks which take place in the traffic create, in the author's opinion, more inconvenience on the whole than if all the traffic sought from the first a different route. The most important thoroughfares in the greatest forwarding town in the world have been repaved with Portland cement concrete foundations within the last six years. The idea of closing them entirely was at first not contemplated, and when it was adopted many complaints were naturally made. Those who know the central three miles of Liverpool-dock streets can well understand this; but it will be shown later on that the loss was rapidly recouped; and since the first few thousand yards of the new pavements were opened, warehouse owners and carriers have alike submitted, without complaint, to the temporary loss, for which they obtain so great a return.

Owing to the mode in which the broken stone is added, the quantity of concrete to be mixed on the boards is less by about 50 per cent. than under the ordinary system. Hitherto the work has been performed by hand, as follows: Each man stands before a board 4 feet square with three sides 8 inches high. The boards are placed in the segment of a circle, touching, or nearly touching, each other, with their open edges towards the center. Behind and between every pair of boards is a frame of galvanized iron supporting a galvanized iron cistern of about 3 cubic feet capacity. From each cistern project two pipes, fitted with roses and taps, one over each board. Hinged to the back of each board is a box, having a capacity of $1\frac{1}{5}$ cubic feet. This box has a strong handle, by which its contents may be readily tipped on to the board. Behind the boards are tipped the gravel and the cement. Suppose the boards to be lettered from A to G. Box A is filled from behind by the gravel man, then B, then C, and so on to G. Mixer A pulls over box A with his spade, and spreads out the gravel, over which the cement boy, who follows the gravel man from A to G, scatters the cement from a hemispherical vessel, containing $\frac{1}{3}$ cubic foot. Mixer A then turns over his gravel and cement, until thoroughly incorporated. He next turns the tap on to a bare part of the board, and shovels over the mixture, scattering it among the spray. An experienced man will scatter the mixture at such a rate that when all turned over it will have exactly the required dampness. The tap is then turned off, and very little more labor is necessary to make the mixture perfectly uniform. By this time a cart or a barrow has arrived from board G. Having discharged the contents of his board, mixer A finds that the gravel man from G has already filled his box, which he pulls over as before, and the whole cycle of operations is repeated. It is obvious that close supervision of such a system is very easy.

One of the most important results effected by the process is perfect mixing with very little water. The concrete is only so far wetted that when squeezed forcibly in the hands a slight dampness appears on the surface. So small is the quantity of water used, that many persons accustomed to concrete mixing have remarked that the mortar will not set properly without more water. Concrete formed with mortar of this consistency can be beaten into a much more compact mass than when a larger proportion of water is used; it is much stronger, and can be formed to a more accurate figure at the surface.

In the earlier trials of this work in Liverpool, the concrete mixing was performed in the street. A carriageway, running, for example, north and south, having been closed, the excavation, commenced at the north end, was proceeded with, at first by carting both northwards and southwards. When a sufficient opening was made the concreting was commenced at the northern end, the mixers being placed south of the concrete, and the materials for concrete south of the mixers. As the concreting progressed, the mixers were moved southwards. It

was found to be impossible to mix so much concrete within the limits of the carriageway as could be laid *in situ* in the same time, and the work was much impeded by the limited space.

In order to ascertain whether any mode of mixing at a short distance from the site could be devised which would not diminish the strength of the concrete, owing to subsequent disturbance in laying, the author tested carefully-prepared samples of concrete, some moulded immediately after mixing, and others moulded, and thus disturbed, at different periods after mixing. In a modified degree the results had been anticipated; but the incorrectness of the prevalent opinion as to the effect of remixing was shown to be much greater than was expected, so far at least as concrete made with good slow-setting Portland cement was concerned.

A summary of the results of four hundred and eighteen experiments, both in compression and tension, which determine this question, are given in the following table (page 245).

Since the time when the first set of these experiments was made, concrete mixing in the street for which the concrete is destined has been abandoned, and any convenient yard or other place has been used, from which the concrete may be deposited within a moderate time after mixing. In the author's opinion, the change has not diminished the strength of the concrete.

It is well known that fresh Portland cement is unfit for use, on account of the large quantity of uncombined lime it contains. If moulded in this condition the lime slakes while the cement is setting, and often breaks it up completely. To avoid this the cement must be thoroughly purged, that is, exposed to the atmosphere for a considerable time. By this means the lime is slaked to a sufficient extent to prevent any failure of the work from subsequent slaking. This action diminishes as the purging becomes more complete; but even in the best Portland cement after exposure to the air for an indefinite time there is rarely a diminution, though there is sometimes an increase of strength if allowed to stand fifteen or twenty minutes between the process of mixing and placing *in situ*. It is difficult to ascribe any cause for this except on the hypothesis that even in the best purged cement there remain minute points of compression, scattered throughout the mass and produced by minute particles of lime, which are slaked on the application of water. Whether or not this be the true explanation, the facts are indisputable, and have an important bearing upon many works in concrete.

The cost per superficial yard of Portland cement concrete foundations in Liverpool, six inches deep, constructed in the manner above described, is as follows:

	s.	d.
0.132 ton Broken stones, including cartage, at 6s.	0	9.5
0.174 ton River Dee Gravel, including cartage, at 5s. 6d.	0	11.5
0.024 ton Portland cement, including cartage, at 52s.	1	3
Labor, mixing concrete	0	3.25
Labor, laying *in situ*, beating and shaping	0	2.75
	3	6
Add for establishment expenses, 8 per cent.	0	3
Total per square yard...	3	9

Bituminous Concrete Foundations.—The positions in which bituminous is preferred to cement concrete, have already been described. It is constructed in Liverpool as follows: On the hard but often irregular bed of the old foundation, previously well brushed, is thrown the required thickness of broken stone of the size of rough macadam. This is well leveled and rolled to the proper form, and over it is poured precisely the same asphaltic composition as that above described for making the joints of sets. The asphalt sinks to the bottom, and fills the smallest crevices between the stones. On the surface, while the asphalt is still warm, is laid a thin stratum of small broken stone, which is thoroughly rolled into the asphalt, and fills up the upper spaces between the larger stones. As in the process of rolling the soft asphalt rises between the smaller stones, still smaller riddlings are scattered over it, until a perfectly true and uniform surface is obtained. In a few hours this

AVERAGES OF 418 TESTS OF PORTLAND CEMENT AND PORTLAND CEMENT CONCRETE, PLACED IN SITU AT VARIOUS INTERVALS OF TIME AFTER MIXING.

Number of Minutes between Mixing and Moulding....	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120
Means of crushing strengths of 24 blocks, 5 parts river gravel, 1 part cement; 1 cube foot each; tested 26 and 28 days after moulding. Tons per square foot.....	45.55	..	..	..	49.00	..	>50.00*	..	48.58	..	47.07	..	45.15												
Ditto, ditto; 24 and 28 days after moulding. Tons per square foot.....	49.57	..	..	..	..	..	>50.00*	..	..	>50.00*	..	..	47.56	..	46.55	..		..	43.55						
Means of tensile strengths of 240 2¼-square-inch sections of pure cement, and Oporto gravel and cement varying from 1 to 1 to 4 to 1; pure cement tested 7 days, concrete 14 days, after moulding. Lbs. per 2¼-square-inches.....	..	602	579	571	604	593	599	594	609	523	498	567	507												
Means of tensile strengths of 144 2¼-square-inch sections of pure cement, and Oporto gravel and cement varying from 1 to 1 to 5 to 1; pure cement tested 7 days, concrete 14 days, after moulding. Lbs. per 2¼-square-inches.....	..	..	593	..	590	..	581	..	578	..	580	..	588	..	581	..	562	..	544	..	566	..	560	..	524

*50 tons was the greatest compression capable of being applied by the machine employed.

surface will bear any amount of ramming without distortion.

The cost per square yard of bituminous concrete foundations in Liverpool, 6 inches deep, is as follows:

	s.	d.
0.153 ton Broken stones, including cartage, at 6s.	0	11
0.041 ton Pitch, including cartage, at 30s.	1	3
1.2 gallon Oil, including cartage, at 2½d.	0	3
0.007 ton Coke, including cartage, at 12s.	0	1
Labor	0	9
	3	3
Add for establishment expenses, 8 per cent.	0	3
Total per square yard...	3	6

CARRIAGEWAYS OF BITUMINOUS CONCRETE, OR ASPHALT MACADAM.

A pavement may be constructed precisely in the same manner as the bituminous concrete foundations above described. It is absolutely impervious to moisture, and in first cost less expensive, though by no means so durable as a stone pavement, or as a rock-asphalt pavement; but, nevertheless, it is sufficiently durable for the numerous back streets of a great town, in which facility of cleansing is of primary importance.

In constructing such pavements it is desirable that the upper layer of large stones should be of smaller size than is necessary for concrete, and that they should not be harder than limestone. The still smaller stones and riddlings should be similarly limited in hardness. The object of this proviso is that the asphalt between the stones may not wear down much more rapidly than the stones, and thus leave in time an uneven surface. The proper consistency of the asphalt is of even more importance than when it is simply used for joints. About 23,000 square yards have been laid in Liverpool, and on sanitary grounds the system will probably be extended annually over large numbers of back streets.

The cost per superficial yard of bituminous concrete pavements 6 inches deep, as constructed in Liverpool, is as follows:

	s.	*d.*
0.144 ton Broken stone and lime-stone chippings, including cartage, at 7*s.* 6*d.*	1	1
0.041 ton Pitch, including cartage, at 30*s.*	1	3
1.2 gallon Oil, including cartage, at 2½*d.*	0	3
0.007 ton Coke including cartage, at 12*d.*	0	1
Labor	0	10
	3	6
Add for establishment expenses, 8 per cent.	0	3
Total per square yard.	3	9

Bituminous concrete is usually prepared in other places by pouring coal tar over broken stones of the size of macadam and previously heated. The stones are then laid, and thoroughly rolled to the contour of the finished surface; after which about an inch of similarly prepared chippings, by preference limestone, is spread upon them and thoroughly rolled.

The author tried this method in Liverpool, but subsequently obtained greater success by the first method described. In some Lancashire towns where the second method is employed, the surfaces appear generally to become disintegrated more readily than those in Liverpool. Recently, however, he has examined some street carriageways laid in Derby by Mr. Clement Dunscombe, according to the second method, and they are among the best artificial asphalt pavements he has seen. As creosote oil cannot readily be obtained in all towns, and as tar can be obtained wherever gas works exist, a knowledge of the details of Mr. Dunscombe's practice and experience would be of great service to the surveyors of provincial towns, even if it does not supersede the first method where creosote oil is cheap.

WOOD PAVEMENTS.

In Great Howard Street, Liverpool, where the traffic exceeds 3,300,000 tons annually, or 216,000 tons per yard width of carriageway, one of the most important hospitals in Liverpool is situated. Near all hospitals it is of course desirable to reduce the noise to a minimum. At first this was done by the use of macadam in the middle half of the carriageway; but the difficulty of main-

taining it became so great, that in 1871 a set pavement was laid. In 1872 the author recommended the substitution of timber. The northern half of the work, about 700 square yards, was accordingly paved in 1873 by the Improved Wood Pavement Company. The site having been excavated and leveled, boards of Baltic pine, 1¼ inch thick, were laid diagonally upon 3 inches of sand, and upon these a second layer of similar boards was spiked. The blocks of wood were of Baltic pine, 6 inches deep, 7 inches and 8 inches long, and 3 inches wide. The ends were placed in contact, and a space of ¾ inch was maintained between each row by a narrow strip of wood nailed to the planking. This space was subsequently caulked with gravel and a bituminous composition. The whole surface was finished with a coating of asphalt and gravel. This work was subject to very frequent repair and was entirely relaid after four years use. The defects were due chiefly to the absence of a proper foundation, for though the blocks had worn down from 2 to 2½ inches during the four years, they would, if properly held in position, have lasted some time longer. The author declined to recommend the further trial of wood in this place unless laid upon a good bed of concrete. Accordingly, in 1877, a pavement, the surface of which was similar to that employed in the first instance, was laid upon a bed of bituminous concrete, constructed as already described, and underlying the plank foundation.

The southern half of the work, about 700 square yards, was also laid in 1873, by different contractors, on a material which was dignified with the name of concrete. The blocks were of Baltic pine, grouted with Portland cement mortar, a material quite unsuited for use in combination with wood. Notwithstanding the consolidating action to which for years the ground had been subjected, the lines of heaviest traffic soon showed signs of sinking, while the adjoining blocks were pressed upwards; and after ten months' use, the pavement became dangerous, and was entirely relaid on the same system, at the contractors' risk. This pavement had to be removed in twelve months, when a wood pavement similar to that originally laid on the northern half was substituted. The pavement shows very plainly the want of a concrete foundation.

In 1874 the pavement of Bold Street, 4,250 superficial yards, was laid by the Improved Wood Pavement Company, in a manner precisely similar to the northern half of the Great Howard Street work. It is a shop street, with a traffic consisting chiefly of carriages, amounting to about 94,000 tons per annum per yard in width; but even here the want of a concrete foundation soon became manifest, though on the whole the pavement has worn, with moderate uniformity, to the extent of about § of an inch in four years.

When it became desirable to continue wood pavement along the upper part of Church Street, the author accordingly recommended a bituminous concrete foundation, 3½ inches thick, which was laid under his direction in 1878. Upon this the Henson Street Paving Company laid their pavement, which consisted simply of pine blocks from Soroka, 3 inches by 6 inches by 9 inches long, separated only by a single thickness of tarred felt, a layer of which was also placed between the foundation and the blocks. A transverse V groove, 1 inch wide, was cut by the contractors in a row of blocks at every 12 inches, ostensibly with the object of preventing horses from slipping. Owing, no doubt, to the nature of the foundation, this pavement has retained its original form better than any wood pavement the author has seen.

The author has not hitherto required the surface blocks of wood pavement to be creosoted, but they have always been selected with the greatest care. The foundation boards when used have been creosoted with not less than 10 lbs. per cubic foot.

In order to maintain a wood pavement in good condition, it is necessary to scatter fine sharp siliceous gravel over it from time to time. This operation adds considerably to the cost of maintenance, but if properly done, it prevents slipperiness; and if not overdone, the little angular pieces become so firmly embedded in the fibres of the wood that they are prevented from rolling, and are gradually worn away on one side only.

The first costs of the wood pavements

most recently laid in Liverpool have been as follows:

COST OF WOOD PAVEMENTS PER SUPERFICIAL YARD.

	s.	d.
Improved wood pavements, as laid in Great Howard Street, in 1877, including double plank foundation.	16	0
Improved wood pavement, as laid in Bold Street, including double plank foundation.	15	3
Henson's wood pavement, as laid in Church Street, including bituminous concrete foundation 3½ inches deep.	15	10

It is scarcely just to wood pavement, however, to compare these figures with those previously given for other classes of pavement. In the case of the wood pavements, the work was executed by London companies; in the case of the other pavements, by the workmen of the Corporation; and the 8 per cent. allowed in the latter case for establishment expenses, would inadequately represent the additional cost necessarily involved in the contract work.

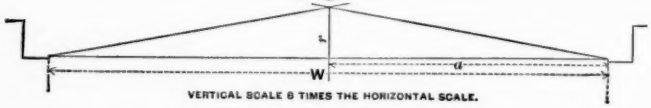
With Liverpool prices at the present time, the actual cost per square yard of wood pavement, with blocks 6 inches deep and bituminous concrete foundation, would be as follows:

	s.	d.
Bituminous concrete.	2	0
Creosoted Baltic pine blocks, pitch grouting, and gravel, including labor.	12	0
	14	0
Add for establishment expenses, 8 per cent.	1	1½
Total.	15	1½

MACADAMISED CARRIAGEWAYS.

There are no thoroughfares near the center of Liverpool, and but few in the outskirts, which are still paved with macadam. The cost of maintaining macadamised carriageways where the traffic is great is so much in excess of the cost of maintaining set pavements; the dirt in wet weather, and the dust in dry weather, are so objectionable; and the quantity of detritus washed from them into the sewers is so large, that for many years they have been abandoned except for a few leading carriage thoroughfares to the outskirts. The proper construction of the substratum of macadamised roads is well known, but not always followed. Much difference of opinion exists, however, as to the best mode of finishing or blinding the surface. The author has tried many methods. Under a 15-ton steam roller, preceded by a watering cart, 1,200 yards of trap-rock macadam, without blinding, can only be moderately consolidated by twenty-seven hours' continuous rolling. If blinded with hard rock chippings from a stone breaker the same area may be moderately consolidated by the same roller in eighteen hours. If blinded with siliceous gravel from ¾ inch to the size of a pin's head, mixed with about one-fourth part of macadam sweepings obtained in wet weather, the area may be thoroughly consolidated in nine hours. Macadam laid according to the last method wears better than that laid by the second, and that laid by the second much better than that laid by the first.

Fig. 1.



CONTOUR OF CROSS-SECTION.

For the purposes of traffic, and traffic alone, the best form of cross section for a carriageway would be a level line, as any cross-fall produces friction, additional traction, and wear and tear of horse and vehicle. But for the rapid discharge of rainfall a cross-fall is necessary. The problem is therefore to design the section in such a manner that the water shall be properly discharged with the least possible mixiumum fall. Suppose the least desirable inclination to be known, if this were adopted as the maximum inclination also, the profile shown with an exaggerated vertical scale in Fig. 1 would be obtained. This profile would be objectionable on the ground of appearance, and

because the breasting would tend to wear hollow.

Having due regard, however, to these considerations, the figure should approximate as nearly as possible to straight lines, meeting at the vertex of the carriageway. If the vertex is slightly rounded, and the breasting still more slightly rounded, a profile is obtained approximating to a hyperbola, as in Fig. 2, and differing widely from the segment of a circle too often adopted, in which the crown is very level and the breasting unnecessarily inclined.

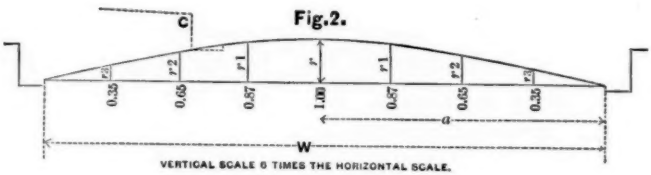
Let a=the horizontal distance from the vertex to the lowest channel in feet.

Let r=the rise of the vertex above the lowest channel in feet.

Let d=the difference of the levels of the two channels in feet.

Let w=the width between the channels in feet.

Fig.2.



VERTICAL SCALE 6 TIMES THE HORIZONTAL SCALE.

For well-made impervious pavements

$$r=\frac{a}{36}$$

When there is a cross fall from channel to channel, the crown or vertex of the pavement is generally placed too near the center, and an unnecessary fall on the lower side is involved. In order that the inclination of the pavement on the two sides of the vertex may be the same, it is necessary to include only that portion of the curve in Fig. 2 which lies between the two channels, when the upper channel is placed in such a position c that the known ratio $\frac{w}{d}$ is maintained.

If $\frac{w}{d}=36$, the figure of the carriageway is half the above figure. If $\frac{w}{d}$ is greater than 36, the figure of the carriageway is greater than one-half of the above figure, and the fall is towards both channels. If $\frac{w}{d}$ is less than 36, the figure is less than half the above figure, and the fall is wholly towards the lower channel.

The height r_1 above the chord line, of a point at the distance $\frac{a}{4}$ from the vertex, should be $0.87\ r$.

The height r_2 above the chord line, of a point at the distance $\frac{a}{2}$ from the vertex, should be $0.65\ r$.

The height r_3 above the chord line, of a point at the distance $\frac{3a}{4}$ from the vertex, should be $0.35\ r$.

In order to apply these deductions to practice the curve in Fig. 2 should be drawn to a large scale for reference. For pavements without cross fall the full curve is to be included. For pavements with cross-fall the upper channel c is to be so placed on the curve that $\frac{w}{d}$ in the street is equal to $\frac{w}{d}$ in the figure, and only the portion of the curve between c and the lower channel is to be taken.

It is thus a very simple matter to set out the cross section of any pavement to the proper curve, when the width between the channels and the difference of their levels are known; and if, in fixing the heights, foremen were always instructed to follow such simple rules, the minimum friction arising from lateral pressure in vehicles, consistent with proper water-discharging power of the pavement, would be attained. The fact that these objects are not always sought must be the author's excuse for bringing such simple matters before the Institution.

Having so designed the cross section of a carriageway, that without unduly increasing the traction, and wear and

tear of vehicles owing to lateral pressure, water runs from it to the channels with maximum efficiency, it is important to consider the best mode of conveying that water to the sewer gullies. The best channels are heavy blocks of hard rock 12 to 18 inches wide, with at least one natural and perfectly smooth face. The slabs should be set upon concrete, with close-dressed joints filled with asphalt, and with a fall of $\frac{1}{4}$ inch per foot towards the curb, and not, as is sometimes done, with the same, comparatively great fall, as the breasting of the pavement, which tends to throw the wheels of vehicles against the curb. The lower edge of the pavement should be about $\frac{3}{8}$ inch higher than the upper edge of the channel. If constructed in this manner a longitudinal fall of 1 in 200 is sufficient to discharge the water rapidly.

II. COMPARATIVE ADVANTAGES OF VARIOUS CLASSES OF PAVEMENTS.

Much has from time to time been written on the relative advantages of various classes of pavements; but the elements necessary to make the statements comparable have always, so far as the author is aware, been absent. Light traffic, and much oftener heavy traffic, is spoken of; but the heavy traffic is often so called, because a few times in the year a heavy boiler or piece of machinery is drawn over it; and, in another case, because the carriageway is crowded with Hansom cabs and other light vehicles. The author has endeavored to formulate the question in such a manner that the results may be generally applied.

With reference to the traffic, the knowledge of three easily ascertained facts is necessary:

(a) The tonnage passing over the carriageway in twelve months.

(b) The width of the carriageway.

(c) The number of wheels on which the twelve months' traffic is borne.

Then $\frac{a}{b}$=the weight of traffic per yard of width, and $\frac{a}{c}$=the number of tons per wheel, giving a fair relative knowledge of the average kind of traffic in various streets.

With respect to the wear of a pavement, the following course should be adopted. If stone sets are in question, one or two rows of sets, the full width of the carriageway, should be taken up and weighed. They should then be carefully replaced, so as to be perfectly flush with the surrounding pavement, and at the end of twelve months again weighed. If the material is wood the exact measurement of a number of sets is sufficient. In addition to the information thus obtained, a street ledger should be kept, giving at a glance the cost per square yard of maintaining every pavement for each year. If, in writing of the relative durability of various pavements, this information were given, an immense amount of experience might be rendered generally available. Without some such information, any statements made can be little more than the opinion of individuals based upon impressions with respect to the traffic, which are by no means always correct.

About 300,000 square yards of stone pavement, constructed as described, have been laid within the last six years, in streets of varying traffic in Liverpool, up to 360,000 tons per yard width per annum, and an average of 0.923 of a ton per wheel including empties—two figures which, taken together, are probably not surpassed, if, indeed, they are equaled, by any other traffic in the world.*

The old pavements in streets of such traffic were generally of the hardest and most durable stone (A and B in the Table page 6), and the foundations, as already stated, of hand pitching; nevertheless, the pavements cost about 3d per square yard per annum to maintain, and they were never in good condition. The hard stone sets B and C, paved on concrete, and with impervious joints, remain in excellent condition. The oldest of these pavements, constructed in 1872, though subjected to a traffic of 218,000 tons per annum per yard of width, and a mean load of 0.679 ton per wheel, including empties, have hitherto cost nothing to maintain beyond the occasional filling up of joints with asphalt, and the restoring of a few sets, not

* The traffic given is that in the dock line of streets. In the average load of 0.923 ton per wheel, empties and light traffic are included.

worn, but split and crushed by loads of 60 tons on four wheels.

The rate of wear under the greatest traffic has not exceeded 0.02 of an inch of solid stone per annum, except at junctions of streets and some other places, where very hard stones were avoided in order to prevent slipperiness.

Under a smaller traffic the macadam opposite the hospital in Great Howard street cost 3*s.* 6*d.* per yard per annnm to maintain, and would now cost 4*s.* 8*d.*; and in the same place wood costs the corporation, including graveling, 1*s.* 11*d.* per annum to maintain. The greater part of this is, however, paid to the company for maintenance, and really, therefore, includes a sinking fund.

These figures serve to show generally the great divergence in the cost of maintenance; but they do not include cleansing, the figures relating to which are still more favorable to the asphalt-jointed pavements. But a much more correct idea of the total difference of cost may be gathered from the table on page 252, in which first cost, renewal, and maintenance are all duly considered.

If the standard of traffic be taken at 40,000 instead of 100,000 tons per annum for every yard in width of carriageway, the figures for the last three pavements are as follows:

Description of Pavement.	Original Cost per Square Yard at Present Prices.	Deductions from first cost to determine cost of Renewal.		Interest on Original Cost at 4½ per cent. per Square Yard per Annum.	Sinking Fund Invested at 3 per cent. Compound Interest.	Maintenance per Square Yard per Annum.	Scavenging* per Square Yard per Annum.	Graveling per Square Yard per Annum.	Total Annual Cost per Square Yard.
		Cost of Foundation not requiring Renewal.	Allowance for old Materials at Date of Renewal.						
	s. d.	s. d.	s. d.	d.	d.	s. d.	d.	d.	s. d.
No. 6. Bituminous concrete pavement.....	3 9	Nil	Nil	2.0	Nil	0 9	2.4	..	1 1.4
No. 7. Wood pavement..	15 1.5	2 0	Nil	7.5	4.3	0 1.0	2.7	5.0	1 8.5
No. 8. Macadam pavement.....	6 9	Nil	Nil	3.4	Nil	1 0	8.0	Nil	1 11.4

*For the figures relating to the cost of scavenging, the author is indebted to Mr. R. S. Reynolds, M.R.C.V.S., who, as chief of the scavenging department in Liverpool, has given great attention to the subject.

¶ While discussing the other comparative advantages of various classes of pavements, the total annual cost as shown by the foregoing Table should be borne in mind.

Pavement No. 1.—In this old form of Liverpool pavement the hard sets of the class A and B, when subjected to slow and heavy traffic, were invariably after a few years pushed from the vertical line, by the backward pressure of the horses' feet, through a considerable angle, often as large as 25°. As the sets on the two sides of the street were pressed in opposite directions, a wave line was assumed by each course. Instead of the whole upper surface of each set being duly presented to the wheels, each surface was therefore inclined, and the wear was confined chiefly to the upper edges. The effect of this in the production of noise may be readily conceived; but as such pavements, though cheaper in first cost, are shown by the foregoing Table to be more expensive than the best class of hard stone pavements, Nos. 2 and 3, it is unnecessary to refer to them further.

Pavements Nos. 2 *and* 3. — These pavements are now exclusively employed for the straight lines of heavy traffic in Liverpool, where the gradients are moderate, and the sets maintain the positions in which they are originally placed. For sometime after the asphalt was worn off the surface, the noise caused by the traffic is considerable, and horses appear much more liable to slip than at subsequent periods. The noise

Table Showing the Total Costs of Various Pavements.

In this table the cost of maintenance and scavenging are reduced to a standard traffic of 100,000 tons per annum for every yard in width of the carriageway. It is assumed that the work is done by the corporation, and 8 per cent. of the cost of both labor and materials is included for establishment expenses.

Description of Pavement.	Original Cost per Square Yard at present Prices.	Deductions from First Cost to determine Cost of Renewal.		Interest on Original Cost at 4½ per cent. per Square Yard per Annum.	Sinking Fund Invested at 3 per cent. Compound Interest.	Maintenance per Square Yard per Annum.	Scavenging per Square Yard per Annum.	Graveling per Square Yard per Annum.	Total Annual Cost per Square Yard.	Remarks.
		Cost of Foundation not requiring Renewal.	Allowance for old Materials at Date of Renewal.							
No. 1. Sets 7½ inches deep. Class of stone A, B. Gravel joints. Hand-pitched foundation.....	s. d. 12 1	s. d. 1 6	s. d. 3 0	d. 6.5	d. 1.8	s. d. 0 1.0	d. 4.2	d. Nil	s. d. 1 1.5	Old Liverpool pavements.
No. 2. Sets 7½ inches deep. Class of stone B, C, D, E, F. Asphalt joints. Portland cement concrete foundation.....	15 1	3 9	3 0	8.2	0.6	0 0.25	2.4	Nil	0 11.45	Pavement now constructed in Liverpool for heavy traffic.
No. 3. Sets 7½ inches deep. Class of stone B, C, D, E, F. Asphalt joints. Bituminous concrete foundation.....	14 10	3 6	3 0	8.0	0.6	0 0.25	2.4	Nil	0 11.25	Ditto ditto.
No. 4. Sets 7½ inches deep. Class of stone G, H, J, K, L, M, N. Asphalt joints. Portland cement concrete foundation.....	15 1	3 9	3 0	8.2	3.7	0 0.5	2.4	Nil	1 2.8	Pavement now constructed in Liverpool for light traffic, or steep gradients, and junctions of streets.
No. 5. Sets 7½ inches deep. Class of stone G, H, J, K, L, M, N. Asphalt joints. Bituminous concrete foundation.....	14 10	3 6	3 0	8.0	3.7	0 0.5	2.4	Nil	1 2.6	Ditto ditto.
No. 6. Bituminous concrete pavement.....	3 9	Nil	Nil	2.0	Nil	1 6.0	2.4	Nil	1 10.4	Pavement recently employed in Liverpool for back streets, and for street carriageways of very light traffic.
No. 7. Wood pavement, blocks 6 inches deep. Bituminous concrete foundation.....	15 1.5	2 0	Nil	7.5	10.1	0 1.0	2.7	5.0	2 2.3	Creosoted wood pavement, if constructed by Corporation.
No. 8. Macadam pavement, hand-pitched foundation.....	6 9	Nil	Nil	3.4	Nil	2 0.0	8.0	Nil	2 11.4	Now only employ'd in Liverpool for suburban roads.

is due to the irregularities of the surface; and the slipping, though on first thoughts it may appear anomalous, is due to the same cause.

Cæteris paribus, a horse is less liable to slip upon a level unpolished surface with narrow joints, 3 inches apart, than upon the irregular surface of new hard stone sets. This may be partly due to the greater traction and partly to the uncertainty with which the horse feels the ground. In the North John Street pavement, the first of the class in question laid in Liverpool, this fact has been very obvious. For the first year of its life the pavement was strongly objected to by the carters on account of the slipperiness; but in this, as in all other cases, the complaints ceased when the larger projections had worn off. Owing, however, to the original existence of those projections, and owing also to the fact that many arrises are unduly broken off, the sets do not wear to so uniform a level as they undoubtedly would if the upper surfaces were better formed in the first instance. With the harder trap rocks and syenities the author believes that a more perfect pavement for heavy traffic than has yet been produced could be formed, if the upper surface of each set were roughly but uniformly dressed. The present method of wearing down the projections by the rolling contact of wheels in street traffic is certainly not an economical method; and if the smoothing were done at the quarries the objections which obtain to the use of such sets in many places, owing to the noise, and liability to slipping which they at first cause, would be in a great measure removed. The time required to wear down such projections, when the sets are properly held in position, may be judged from the fact that in North John Street almost every other set still shows hollows which originally existed in the surface, and which the wear of a total traffic in six-and-half years of about 1,417,000 tons for every yard in width has not yet reached. The difficulty of sufficiently dressing one surface of such sets by hand is no doubt very great; but the design of a machine for the purpose is well worthy of attention. The problem must not be confounded with that involved in the dressing of any ordinary rock, even the hardest used in building, or even with that of dressing granite for paving purposes.

Pavements Nos. 4 *and* 5 have been employed in Liverpool for light, quick traffic, or where the gradient is too great for pavements Nos. 2 and 3, and at the junctions of streets where, in turning corners, horses are more liable to slip. Each stone classed under this and the last head has its own peculiarities, which are explained, so far as possible, in the table at page 240. They all wear much more rapidly than those of the last class, but some of them, while absolutely free from slipperiness, wear flat, and retain their arrises. On this account they are remarkably suitable for quick traffic, and produce but little noise. The stones in this class wear so readily to a uniform surface, that it would not be worth while to dress their surfaces as is suggested in the last case.

Pavements Nos. 2 *to* 5 *inclusive* may be classed together with regard to cleanliness and traction. They are easily cleansed, and the result of a single sweeping is most satisfactory. They are remarkably free from dust in dry weather, and from mud in wet weather.

Some years ago, the author considered the desirability of testing the traction on various pavements by a dynamometer; but subsequent observation convinced him that such a course would only give misleading results. The work capable of being performed by a horse in drawing a load is dependent, not only upon the absolute power required to move the load at a certain speed, but also, and in a high degree, upon the uniformity of the resistance, and upon the ease with which the horse travels — depending again upon the uniform roughness, if the term may be applied, without such irregularities as cause uncertainty in feeling the ground.

The author decided, therefore, to draw his conclusions from a broader basis; and fortunately, the actual increase of work performed on the new pavements is so great, that there is no difficulty in doing this. It appears that in those lines of traffic in which pavements Nos. 2 to 5 inclusive have been substituted for pavement No. 1, the ordinary load of two horses has been increased by about 1 ton, and of one horse by about ½ ton. There is a

general impression also that the speed even of the heavy cartage has been increased; if from no other cause, this is probably owing to the comparative absence of blocks in the traffic, for the speed of the quicker traffic is undoubtedly increased, and for a given traffic any given area of pavement is less crowded than before. The cost of maintaining vehicles is also stated to have been much reduced. It is difficult, however, to arrive at any absolute figures for the saving in wear and tear of horses and carts; but from the above data, taking the actual cartage rate of 1*s.* 6*d.* per ton, there is a saving in cost of cartage alone exceeding £10,000 a year for every mile of such a pavement as is now laid in the dock line of streets in Liverpool. This estimate can only be approximate; but the author is satisfied that if the wear and tear of horses and carts could be included, the £10,000 per mile would be found to be considerably less than the actual measure of the benefit, apart from cleanliness and reduction of noise and cost of maintenance, which the public derive from comparatively perfect pavements. In the streets of quick traffic the actual loads conveyed may not be greater, but there is certainly a reduction in the wear and tear of horses and vehicles, and an increase of speed.

The author has in this paper devoted much attention to the consideration of pavements for streets of heavy traffic, as he is satisfied that in most of the great forwarding towns such pavements have received too little attention. It is no uncommon thing to find in the heart of the heaviest traffic of large towns, both in this country and abroad, pavements constructed of boulders, or of sets so indifferently laid as to move under every passing wheel. The older pavements of Liverpool were indeed excellent as compared with many elsewhere. If the authorities of such towns took a broad view of the subject, they would at once see the great loss to the trade of the country in general, and of their own towns in particular, which the continuance of such pavements causes.

In connection with pavements for heavy traffic, the use of stone tramways,* such as those employed on London Bridge, has often been advocated. With the pavement No. 1, as formerly constructed in Liverpool, tramways of perfectly smooth Penmaenmawr rock have been largely used. The stones were 12 to 18 inches wide, and were appreciated by the carters; though, owing to the limited width of the carriageways, the number of standing carts, and the varying rates of the vehicles, constant diversions from the line took place. This inconvenience is not, of course, felt to the same extent on a bridge.

When the impervious asphalt-jointed pavements were introduced, stone tramways were in some cases again employed; but it soon became obvious that they were no longer appreciated; and it was by no means uncommon to see the horse walking on the tramway stones drawing a load with wheels on the sets. The difference in traction was, in short, no longer perceptible. Replies to inquiries made of the Liverpool Cartowners' Association, and other large carriers, have supported this view, and tramways have been discontinued in all ordinary cases. Stone tramways are the outcome of defective pavements. Under heavy traffic they are exceedingly difficult to maintain in a stable position. They induce exceptional traffic on the sets adjoining them, and therefore cause grooves to be formed. In crowded streets, even on bad pavements, their utility is but slight; while on good pavements they are worse than useless.

Pavement No. 6, of bituminous concrete is shown by the table to cost ultimately 1*s.* 10 4*d.* per yard for a traffic of 100,000 tons per yard of width. This is considerably more than stone set pavements, when laid in the best manner. It is not, however, suitable for streets of greater traffic than about 40,000 tons per of yard width per annum; and in such a street the annual cost of maintenance of bituminous concrete is so much more reduced than that of the stone pavements, that the prices become about equal, as is shown by the second table, where the standard traffic is taken at 40,000 tons per yard of width per annum. In every town, whether great or small, there are many streets of dwelling-houses through which only the local traffic passes, and for such cases this pavement is admirably adapted. Wheels

* Called in some towns "wheelers," with as much reason as stones to be broken for macadam are called "breakers."

make as little noise upon it as upon rock asphalt, and horses' shoes make less; while it is moderately easy to cleanse.

Rock Asphalt Pavements.—In 1871 the author investigated the subject of the Val de Travers and other rock asphalts. If it had been possible to adopt asphalt pavements for any considerable section of the Liverpool streets, there can be little doubt that the system would have been commenced. Moderately level streets exist in Liverpool running north and south, but nearly all those running east and west have inclinations, upon which such pavements would be undesirable. Rock asphalt pavements have therefore not even been tried in Liverpool. It is to be hoped, however, that the experience of metropolitan engineers will enable a comparison between rock asphalt and other pavements to be made in the course of the discussion on this paper, on the principle adopted in the tables on pages 251 and 252.

No. 7, *Wood Pavement.*—To a number of energetic companies the successful introduction of wood pavements into this country is due. The stimulus given by the existence, or, in some cases, the fancied existence of several patents has initiated a work, which, under other circumstances, would probably have been long delayed. Beyond a keen and useful competition, however, the patented inventions have not, as a rule, produced any special advantages, and the best forms of wood pavement are now probably open to any one to construct. This being the case, the author has at pages 251 and 252 taken the cost of wood pavements, if constructed like the stone pavements of Liverpool by the Corporation. Even under these conditions it is clear that wood pavements must be regarded as luxuries when compared with the best stone pavements, though for traffic approaching or exceeding 40,000 tons per yard of width per annum they are less costly than macadam. Wood pavement, however, has not, in the author's opinion, been yet constructed in the best manner. When first introduced into this country, it was thought necessary to provide foothold for horses by keeping the blocks from ½ an inch to 1 inch apart. The consequence was, that the fibers being spread by the traffic, absorbed impurities and wore away unduly. Experience has shown, however, that a close-jointed wood pavement, properly graveled, is not more slippery than a wide-jointed wood pavement also properly graveled. In the former the fibers cannot spread, and the little grains of quartz are much more firmly held in position than in the latter. Nor does it appear that creosoting makes the blocks when properly graveled more slippery.

Wood pavements having wide joints, or imperfectly laid upon yielding foundations, have properly been objected to on sanitary grounds; but between these and close-jointed pavements upon concrete foundations there is a wide distinction; and although creosote is of little use where the fibers are liable to spread, it would greatly diminish absorption if applied to the extent of 12 to 14 lbs. per cubic foot, where the joints are close and where the fibers cannot spread. Under the most favorable conditions, however, wood pavement cannot be so efficiently washed, or otherwise cleansed, as asphalt-jointed sets, or rock asphalt, though in this as in all other respects it is to be preferred to ordinary gravel-jointed stone-set pavements or macadam.

No. 8, *Macadamized Carriageways.*—Of all pavements macadam appears to the author the least satisfactory for street carriageways in which the traffic exceeds about 30,000 tons per yard of width per annum. It is the most costly, the dirtiest, and, on the average of all kinds of weather and all conditions of repair, probably involves a greater traction for a given load than any of the other systems when thoroughly well laid. Its dirtiness consists, not only in the excessive mud of wet weather, and the excessive and impure dust of dry weather, but also in the facility with which organic impurities are absorbed by it, decomposed within it, and exhaled to the atmosphere. In country, and in some suburban roads the extent of this objection is insignificant, and no other pavement is better than well maintained macadam; but in some of the carriageways of the west end of London one would regard it as intolerable, had it not been tolerated so long. To the unsophisticated provincial the manner in which, on a hot July day, fashionable London rolls over her tainted macadam pavements, apparently without even

smelling them, is a mystery almost as great as surrounds the fact that the metropolis, alone among the great centers of civilization in this country, if not in the world, still submits with apparent satisfaction to an intermittent water supply, impure at times in almost every household, however pure the source of that supply may be, when with absolute pecuniary benefit a constant supply might be obtained.

ON AN INCLINED RAILWAY AT THE GIESSBACH, SWITZERLAND.

By R. ABT.

From "Abstracts" of the Institution of Civil Engineers.

THE cascade of the Giessbach, on the lake of Brienz, has of late years become a favorite resort of Swiss tourists, and to meet the demand for accommodation a large hotel has been built. This is placed on a cliff, about 303 feet above, and 1100 feet back from the lake, from which it is separated by the channel of the Giessbach, the approach being by a circuitous footpath on the right bank of the stream. In order to render the place more accessible, a concession was granted by the Swiss Government, in December, 1878, for the inclined railway described by the author.

This is a single line, with a middle crossing place, on the meter gauge, with a central rack rail. The average gradient is 28 in 100, rather more than half the total length (187 meters out of 346 meters) being carried upon a wrought-iron bridge of five spans of 38 meters each. These are arched trusses; the roadway is carried by a straight [iron beam, weighing 28.23 kilogrammes per meter, above a segmental arch of ⊥ section of 27.25 kilogrammes per meter; the two members, which are 6.20 meters vertically apart at the springing, and 1.07 meter at the crown of the arch, being united by struts and diagonal ties of ⌊ iron, from 13 to 9 kilogrammes per meter. The roadway is formed of –∩– iron (*zores*) cross beams, 15.5 kilogrammes per meter, placed at intervals of 1 meter, which carry the plank footway, 60 centimeters wide, besides doing duty as sleepers for the rails. The crossing place for the carriages is on the bottom span, which is therefore wider and heavier than the others, its total weight being 18 tons, or 0.497 tons per lineal meter; the other four spans weigh respectively 15.6, 11.8, 11.8 and 10.6 tons, making a total of 68 tons for the whole bridge. The piers and abutments are in dressed masonry. The rails are of wrought iron, flat-bottomed, and weighing 16.75 kilogrammes per meter. On the bridge they are attached by cast-steel shoes clipping the flanges to the iron cross sleepers. When the line is in earthwork, oak sleepers, and iron spikes of the ordinary pattern, are used. The rack rail is made with] iron sides, and teeth of trapeziform section, having a pitch of 101 millimeters riveted through them. It is put together in segments of 3 meters long, weighing 96 kilogrammes, or 32 kilogrammes per meter, and is carried by continuous longitudinal beams of ⊢ iron over the wooden sleepers.

The traction is on the water-balance system, the descending carriage drawing up a second loaded one by means of an excess weight of water carried in a tank in the under frame, the two being united by a steel wire rope passing over a reversing pulley at the upper end of the line. The rope weighs 700 kilogrammes; it is made of the best English cast steel, of a total section of 2,198 square millimeters in seventy wires, of 2 millimeters diameter; has a breaking strain of 30 tons, or about 150 kilogrammes per square millimeter. The carriage is about 11 meters long, divided into six compartments, one for luggage, and the other five with seats for forty passengers; it is carried on six wheels, of which the two uppermost are a transverse axle carrying the toothed wheel and the brake drum; while the other four are attached to a

bogie frame of 2.2 meters base below. The distance from the center of the bogie to the upper axle is 4.5 meters, giving a total wheel base of 5.6 meters. All the wheels have bronze bearings and run loose on their centers. The brake drums are of cast steel, 52 centimeters diameter, and the brake blocks of bronze. A safety catch, formed by a toothed rod, is attached to the coupling hook, which, in the event of the rope breaking, falls into the hollow of the rack rail and stops the carriage. The wheels of one carriage are flanged on the inside, those of the other on the outside, of the rail; so that, on arriving at the crossing point, one invariably goes to the right and the other to the left. The total weight of the carriage empty is 5.3 tons; the capacity of the water cistern is about 5½ tons.

The load to be lifted varies from 6 to 9½ tons, which corresponds to a descending counterpoise of between 7.3 and 10.8 tons, or the amount of water expended at each trip may vary between 1.6 tons and 5.8 tons. The latter quantity can be filled and discharged in about a minute.

The maximum speed allowed by the concession is one meter per second, making 346 seconds, or about 6 minutes for the trip; a speed which, the author remarks, may be considered as somewhat snail like, but nevertheless, when compared with that of the Swiss lines, with with the ordinary valley gradients of about 6 in 1000, represents a comparative duty; the 93 meters of vertical height corresponding to a length on the lower gradient of 15.6 kilometers, and to traverse this in 6 minutes a speed of 156 kilometers per hour, or double that of the fastest express train in England, would be required. About 4 minutes are required for the necessary operations of loading and unloading the carriage at either end; so that the trains succeed each other at intervals of 10 minutes during the working season, which lasts from 15th June to 15th September usually.

The works of the line were commenced at the end of October, 1878, and the line was opened for use on the 20th of July following. The cost is stated at 146,880 francs, and the annual working expenditure at 3,640 francs. At the close of the first working season on the 30th September, 1879, one thousand eight hundred trains had been run, carrying twenty-eight thousand persons without the slightest accident. The total receipts were 18,300 francs, equal to a gross return of 9.97 per cent. on the capital, or allowing 5 per cent. as interest, and 4 per cent. as a reserve fund for renewals, there was nearly 1 per cent. surplus, apart from the amount saved in transporting provision, stores, coal, and other heavy articles to the hotel.—*Die Eisenbahn.*

REPORTS OF ENGINEERING SOCIETIES.

AMERICAN SOCIETY OF CIVIL ENGINEERS—The latest Number of Transactions contains:

Paper No. 212. "The Strength of Wrought-Iron Columns," by G. Bouscaren.

Paper No. 213: "The Improvement of the Harbor of Quebec," by J. Vincent Browne.

THE ENGINEERS' CLUB OF PHILADELPHIA. At the last meeting the Standing Committees of the Board of Directors for 1881 were appointed as follows:

On Finance—Frederic Graff and J. J. de Kinder; *On Membership*—J. J. de Kinder, Geo. Burnham, Jr.; *On Publication*—Rudolph Hering, Geo. Burnham, Jr.; *On Library*—T. M. Cleemann, Fred. Graff.

Mr. Morris exhibited a photograph of a machine designed by Mr. Wm. S. Auchinchloss, which will solve problems of various kinds, involving proportion, alligation, involution, evolution, etc.

Mr. Charles A. Ashburner, Chairman of Committee on Information, presented a paper upon the progress and methods of the Pennsylvania State geological survey. Forty-eight counties have been entirely completed, eighteen counties partially surveyed and seven counties remain to be surveyed. The Board of Commissioners estimate that it will require three years to complete the survey of the entire State. He also read notes on mine topography, in which a new method was proposed for determining the area of the available coal in the anthracite region, and cited an instance in which the hypothesis of the method had been sustained by after developments. He also exhibited a complete set of specimens of the crude and refined petroleums from Barku, Galicia and other European fields, recently received through Hon. Lewis Emery. He also presented a paper by Colonel James Worrall, member of the club, upon the routes and methods which have been proposed for crossing the Isthmus. The Panama, Nicaragua and Tehuantepec canal routes and the ship railroad of Captain Eads were treated, forming a paper too comprehensive to be fairly treated in a short abstract.

Mr. T. M. Cleemann read a paper on the

strength of wrought-iron columns, showing that the accepted formula of Rankine & Gordon gives imperfect results, and urging the necessity of further experiments on various shapes in order to complete it and render it more exact. Professor L. M. Haupt read a paper on intercommunication in cities, showing the great value of increased facilities of travel, and applied them specially to Philadelphia. The number of persons using the horse cars during the last year was about one hundred million, and the value of a saving of one mile in distance, and its equivalent in time and power, was computed upon this basis, with some surprising results. The paper was limited to a consideration of the street system only, the railroad system being reserved for the future. The paper contained some valuable suggestions as to important proposed improvements.

ENGINEERING NOTES

THE Leggestein tunnel, near Wasen, the first curved tunnel on the St. Gothard line was completed on the 16th inst. It is 3,280 feet long, and has been bored through hard granite entirely by hand labor, as, owing to the absence of water power, perforators could not be used. The contractors are profiting by the present fine weather to hasten the completion of the works, which are progressing much more rapidly than was expected at the beginning of the winter.

THE Severn tunnel works are being pushed forward with great energy. Four hundred men are employed, and the large pump, specially made for the purpose from the instructions of Mr. Richardson, C. E., is now throwing about 3,700 gallons of water per minute. It is hoped that the underground works will shortly be freed from water. Upon the Gloucestershire side a small portion of the masonry of the tunnel has been completed, and Mr. Walker, the contractor, is getting the work well in hand.

ON Saturday last an interesting experiment was concluded at the new iron quay in course of construction for the Great Eastern Railway Company at Ray Island, Harwich. In the beginning of last spring a number of iron screw piles, which had been placed in position, but not braced together, were overturned by a slip of the earth embankment immediately behind them, and it has been found necessary to remove these and replace them by others. It was with this object that on last Saturday week Mr. G. N. Abernethy, the resident engineer, accompanied by Lieut. W. Almack, R. N., of H. M. S. Penelope, proceeded to attempt to remove the large screws, 4ft. diameter, which form the base of the pile. This was done by firing a 1 oz. charge of "tonnite" placed in the interior of the pile at a depth of 36ft., and ignited by electricity, it being found impossible, on account of the accumulation of mud in the pile, to insert the charge any lower, the piles actually being 48ft. long, and imbedded 37ft. in the mud of the river. The experiment was successful, and on Saturday last the pile, 36ft. long, 2ft. diameter, and 1in. thick, was drawn by Mr. T. Vaux's powerful tug, and landed on the quay, when it was found to be neatly fractured at the point of discharge. The tonnite, manufactured by the Gun Cotton Company, is a comparatively new explosive, and is said to be much more safe for use and transport, and equally as strong as dynamite.

THE PROPOSED NEW TAY BRIDGE.—As already mentioned, the plan adopted for the restoration of the Tay Bridge involves the complete abandonment and removal of the existing viaduct. The structure to be substituted for the abandoned bridge will be erected a little higher up the river, and will carry a double line of rails. It is understood that the engineer has devised a remedy for the objection raised last year to the junction of the Newport Railway with the bridge line, and that the other recommendations of the Special Committee will be given effect to, so that all opposition to the Bill intended to be introduced next session may be avoided. The cost of the works will be very considerably greater than was anticipated in the application to the Parliament made last session; but the arrangements contemplated are such as, it is believed, should remove all doubts as to the absolute stability of the new structure.

THE SUEZ CANAL.—The revenue of the Suez Canal Company has made a great bound upwards this year. The total receipts to August 31, were £1,100,820. The corresponding revenue in the corresponding period of 1879 did not exceed £800,764.

IRON AND STEEL NOTES.

IRON MANUFACTURE: ENGLISH AND AMERICAN.—The *Engineer*, in an editorial article on general progress in 1880, says of the iron trade:—Our great competitor is the United States. In that country iron ore and coal abound, and the production of manufactured iron and steel of all kinds has been greatly developed and fostered by protection. We regret to say that some of our own ironmasters and others prognosticate that in a comparatively short time the United States must adopt free trade; that when this is done there will be great demand for British iron and steel, and that if we can only rub along a little longer we shall yet do very well without making undue exertions. We have heard this argument used year after year for many years. It is fortunate that no matter what turn men's thoughts take in this direction, their actions do not run wholly in the same groove. There is not the slightest probability now that there will be any mitigation of the tariffs in our favor until the next presidential election, four years off. Those who hold different opinions assert that the farmers will rise against protection; but the truth is that the American farmers suffer very little, if at all, from high import duties. The American farmer has practically no rent

to pay, and he can therefore very well afford to contribute to the prosperity of large towns by submitting to the infliction of the tariff. At this moment the United States are the most prosperous nation on the face of the earth; they are practically self-sufficing, and it is very difficult to see what they could gain yet awhile more than they have by adopting free trade principles. There is in truth no analogy at all between such a country as America and such a country as Great Britain. The facts being as they are, ironmasters in this country ought to see that no effort should be spared to put themselves on a footing of equality with their competitors. It is quite certain that at present we are not holding our own in this respect. The United States ironmasters are beating us by 100 per cent. in the output from their plant. With one pair of converters they can do as much and more than we can do with two pairs; and while our blast furnaces turn out 480 tons of pig per week, theirs, much smaller, give as much as 1,100 tons a week. In the rail mills, and bar and sheet mills, matters are in much the same condition. If we are asked, To what is this superiority due? we reply that it is to be traced, to some extent, to better organization, and in others to better plant. In the Bessemer works, for example, the drill of the men employed is perfect, and a converter is never stopped for days while being lined up and re-bottomed. The converter alone represents but a small part of the plant; but when a converter is standing, so, to a certain extent, do the blowing engines, the hydraulic appliances, ingot molds, and very probably the hammer, the cogging mill, and the rail train. What would be thought of a foundry which was closed while a 5-ton ladle was being re-lined? In the United States, for a long time back, the moment a converter is burned out it is taken away, and a new one put in its place. The operation requires, we understand, about half-an-hour at the most. In how many English steel works is the same plan pursued? It has, we may say, been forced on Messrs. Bolckow, Vaughan & Co., by the necessities of the basic process, and we hope to see it generally adopted before many months are out. There is still room for invention in this direction. Bessemer plant was regarded as perfect until the other day among ourselves. Then Mr. Holley showed the good people of the States that, excellent as it was, it could be made better. Is it to be supposed that Mr. Holley has left our own Bessemer steel men nothing to do? We think not. Mr. Windsor Richards, in his recent address to the Cleveland Institution of Engineers, spoke in somewhat depreciatory terms of the work done by the Edgar Thomson Steel Company, suggesting that by hard driving, the furnaces were soon burned out and wanted re-lining. Even if we admit this to be quite true, it seems to be perfectly clear that the cost of re-lining must be charged as so much per ton of iron made, and that unless it can be proved that the Edgar-Thomson furnaces cost more for repairs and renewals per ton of pig than do furnaces less hard pressed, the advantage is altogether with them. To make this plain, let us say that one of our great Cleveland furnaces, with its appurtenances, cost £20,000, which is not far from the truth. It turns out, say, 450 tons of pig iron per week, or 23,400 tons a year. The interest on £20,000 at 5 per per cent. is £1,000, or 20,000 shillings; consequently each ton of pig iron must be charged with, say, 10d. for interest alone. If, however, the make of the furnace had been doubled, or 900 tons a week, then 5d. a ton would have been saved, and this sum, and less, represents in the present day a profit which is by no means to be despised. It comes to nearly £20 a week per furnace, and even this amount of clear profit, small as it is, many an ironmaster would be glad to get from each of his blast furnaces. It may be said that, after all, the rate at which a furnace is driven has very little to do with mechanical engineering. But this is not true; double production means double blowing, double feeding, double hoisting of materials, and increase in the power of various appliances, all of which demand renewed exertion on the part of the mechanical engineer. And here we may refer to a somewhat novel pair of blowing engines, recently put down at Staveley, where they were constructed from the designs and under the superintendence of Mr. Charles Markham. We shall illustrate these engines in an early impression, and it will be enough now to say that they combine in an unusual degree great power with considerable economy of fuel and very small first cost. A great deal of the blast furnace plant of Great Britain is antiquated, and the sooner it is replaced with more modern plant the better. We may cite as an example hot blast stoves. It is a suggestive fact that much of the success which attends the labor of the American ironmaster is due to the efficiency of Mr. Cowper's stoves, and yet English ironmasters have been very slow to accept an invention which American ironmasters jumped at.

THE STEEL TRADE.—The great increase in the manufacturing capacity both of Europe and America has alone prevented that return to high prices which the present demand would have caused; and as, on both sides of the Atlantic, factories are being still further extended, the same counteracting cause will have effect for some time to come. A year ago, the total output capacity of steel rails in England was rather more, and in America rather less, than 750,000 tons per annum, while now, with the works already in operation or ready to commence at short notice, the total in each country is about a million tons. In America the present demand for steel rails is so considerable as to tax severely the supplying power available, and the product for at least six months forward is already sold. A deficiency does not at first result in the importation of rails from Europe, but in the supplementing of that department of manufacture which falls behind. Thus, while the demand for raw material is generally sufficiently met by Italian or Spanish ores, Bessemer pig iron has to be imported when the local blast-furnaces prove insufficient, and,

in other cases, when the blooming mills cannot keep pace with the converters or with the rail mills, a considerable import of blooms from Europe takes place. This is the case at present, not only for rail making, but also for supplying those smaller steel works which make plates, wire, and other miscellaneous goods, with the blooms and billets the large converting works are at present too busy to supply. If the rail mills in America cannot meet the demands of purchasers during the coming year, it is yet an open question whether the deficiency will be made up by imported steel rails, or by home-made iron rails, or by iron rails from Europe. Both in Europe and America the different modes of making steel are finding their proper place. The Siemens process, with all its acknowledged merits, cannot compete with the quicker Bessemer converters for so cheap a commodity as steel rails. In England, steel works constructed with the Siemens open-hearth plant are not working on rails, but are making ship plates, railway tires, axles, and other similar articles, or are stopped altogether; while in America the Siemens process has hardly been applied at all to rail making, and the Siemens furnaces, with or without the Pernot modification, are confined entirely to the smaller industries, and are found extremely convenient for using up the Bessemer scrap. Both in England and America the circumstances of locality and transport are acquiring enhanced importance in the competition of trade; but while in England even a short land carriage is a disadvantage, in America works unfavorably situated for material are compensated by their contiguity to local consumers.—*Matheson and Grant's Engineering Trades' Report.*

RAILWAY NOTES.

NINETY MILES AN HOUR BETWEEN PHILADELPHIA AND NEW YORK.—At a recent regular meeting of the Franklin Institute in Philadelphia, W. Barnet Le Van read a paper on "Ninety miles in sixty minutes; or, how to accomplish the distance between New York and Philadelphia in one hour." It was a continuation of one read by him some time ago on high railroad speeds, and undertook to show the difficulties in the way of running trains at this high speed at present, and how they could be overcome. In the paper the distance in an air line between New York and Philadelphia was stated to be 80.09 miles, over a comparatively level country. The existing roads are far from being straight. On the Pennsylvania line, in the 88.4 miles between Philadelphia and Jersey City, there are 84 curves (15 in the 15 miles between Germantown Junction and Schenck's). The greatest length of straight track—between Philadelphia and Trenton, does not exceed three miles, and the greatest in the entire road does not exceed 10 miles. The Pennsylvania Railroad is not responsible for this condition of the road, but has in fact done much to straighten the line, and, notwithstanding these drawbacks, runs trains on the road at the rate of 50 miles per hour. On the Bound Brook Route there are 43 curves; one on the bridge crossing the Delaware River, which has a radius of 2,865 feet, is 1,837 feet long, and ascends 19 feet to the mile. The greatest stretch of straight track is from Skillman's east—14 miles. To compensate for the centrifugal force tending to throw the cars from the track when running at high speed on curves the outer rail has to be raised. On a curve of three degrees radius, the super-elevation required on a guage of 56½ inches, while less than five inches at 50 miles an hour, would have to be 16 inches at 90 miles per hour. On the Pennsylvania road the super-elevation is one inch for each degree of curvature up to five inches, which is the limit. The speed must be reduced beyond that to correspond with the curve. This is one of the limitations put upon high speed on existing roadways. Mr. Le Van considered others at great length, and summed up by saying that, after a careful study of the subject, he was satisfied that a paying road could be built to be run in a straight line between New York and Philadelphia, reducing the distance about 10 miles and enabling trains to be run through in 60 minutes. One of the means of effecting this purpose would be a reduction of the dead-weight in the trains. The fast trains now running between Philadelphia and New York have generally four cars with engine and tender, weighing 232,000 pounds, or 116 tons dead load, and are 264 feet long. For from four to eight tons of passengers carried, trains are made up weighing from 110 to 150 tons. Mr. Le Van thought it would pay to build a line so perfect in all its details as to exclude rival lines, and attract to itself all the through business. The line he pictured crossed no roads at grade, and had only two curves of 10,000 feet radius each.

ST. GOTHARD RAILWAY,—An account of the Leggestein spiral tunnel, which is one of the most remarkable works in connection with the St. Gothard Railway, has been communicated to the *Daily News* by the Geneva correspondent of that paper.

"The leading feature of the scheme adopted by the engineers in constructing the line has been to keep to the bottom of the valleys—on the north side of the Alps, the valley of the Reuss; on the south side, that of Ticino—and, so long as they did not deviate too widely from the required direction, to follow their windings until the point fixed for the entrance of the great tunnel should be reached. When this could not be done, and it became necessary to carry the railroad higher spiral, or to use the German term, 'turn tunnels,' were to be pierced through the mountains. These tunnels made at once a steep gradient and a sharp curve. The gradient of the Leggestein tunnel is 23 in the 1,000, and it describes a curve of 300 meters. After leaving it, the line winds spirally outside the mountain, and passing through a shorter passage higher up, reaches the required altitude. The construction of this tunnel was difficult, less on account of its length, which is nothing extraor-

dinary, than owing to the necessity of boring entirely by hand through a mass of almost impenetrable granite. The progress made at the outset did not exceed three decimeters (twelve inches) in twenty-four hours, even with the aid of blasting. The necessity of handwork arose from the absence of water, and the impossibility, in the circumstances, of using steam for the perforators. Two other turn tunnels—in the valley of the Reuss—that of Wellington, 1,000 meters long, and that of Pfaffensburg, 1,000 meters long—will be completed during the coming spring. The former, like the Leggestein, is being bored by hand, the latter by water power. On the south side, in the valley of the Ticino, there are four tunnels (which are to alpine railways what locks are to canals), of from 1,500 to 1,600 meters long, now in course of construction. All these are being bored by water power, and like those on the north side are expected to be finished early in 1881. It is intended to light the great tunnel by electricity. To this end two systems have been proposed. One is to place in the passage 40 electric lamps, each possessing a capacity of 1,200 candles. The interval between each lamp would be about 400 yards, and the necessary motive power would be supplied by the turbines at Airolo and Goeschenen, which have been used for moving the perforators and ventilating the workings. The second proposal, whether it be practicable or not, has certainly the merit of greater originality. According to this scheme, a locomotive impelled by compressed air would be stationed at either portal of the tunnel. These locomotives, being smokeless, would be used for drawing the trains through the tunnel. Each locomotive would carry two electric lamps, and two would be placed at the end of the train, together with reflectors, so arranged that their united light would be equal to that of 12,000 candles. By this means, wherever there was a train, and for a considerable distance before and behind it, the tunnel would be brilliantly lighted at a comparatively trifling expense, the electricity being produced and the engines provided with their motive power by the turbines at Goeschenen and Airolo."

ORDNANCE AND NAVAL.

RESULTS OF EXPERIMENTS AT CRONSTADT WITH A 9-INCH MORTAR AGAINST AN ARMOR-PLATED PLATFORM, OR HORIZONTAL TARGET.—The shape of the platform was rectangular, 70 ft. in length by 35 ft. in breadth, and it was composed of two layers, each consisting of 50 plates, the thickness of the upper layer being 2 inches, and that of the lower 1 inch. The two layers were united by rivets 1.13-in. in diameter.

Under the plating, and in the direction of its breadth, were placed baulks 8.4-in. square at a distance of 3 ft. 5 in. from center to center, to which the plates were bolted by means of conical-headed holts 1.13-in. in diameter. Under the baulks were three longitudinal beams 8.4-in. square. At the points of intersection of these with the transverse baulks, the bolts served to connect them as well as the plating together. These beams rested upon sleepers of the same section which were supported upon 50 piles 15.7-in. in diameter, driven 5 ft. into the ground. The total height of the mass from the ground to the upper surface of the plates was 5 ft. 11 in.

The 9-in. rifled mortar of steel, loading at the breech, was placed behind a parapet in such a manner that an artificial alignment was needed to lay it by. The weight of the mortar including the breech fastening is 114 cwt. The maximum charge is 18 lbs., giving a range of 5,400 yards at an elevation of 45°.

It was mounted on a provisional iron carriage, on the Semenoff priuciple. The elevation was effected by means of toothed wheels. The distance of the mortar from the platform was 2,432 yards.

Three kinds of projectiles were fired—ordinary cast iron, hardened cast iron, and hammered steel.

The weight of the first was 271 lbs. The shells of hardened iron were loaded with sand to a weight of 278 lbs., or with powder to 280 lbs. In the latter case the bursting charge did not exceed two lbs., and the weight was made up with lead.

The steel shells were fired either quite empty, and weighing on an average 265½ lbs.; or loaded with from five to six lbs. of powder, to bring them up to a total weight of 271 lbs.

A trial of five shells of ordinary metal proved the laying of the mortar, and determined that for an elevation of 45° the proper charge was 8.36 lbs.

Of the following 36 shells of ordinary metal, none hit the mark. Increasing the charge to 8.59 lbs., out of six shots at an angle of 44° there were two hits, but their effects were very small, and the two projectiles were broken to pieces.

Next were fired 28 shells of hardened metal, at an angle of 51°, with a charge of 9.94 lbs. There were five hits out of these in spite of very unfavorable atmospheric conditions.

The effects were considerable; the two layers of plates were penetrated, even when the projectile encountered a baulk. The bolts were broken and the timber work damaged, but in most instances the shells broke up.

Steel shells empty were then fired with a charge of 9.94 lbs., at an elevation of 57°. Three shells out of eight hit. The effects were much superior to those obtained with the hardened metal shells, although the weight of the latter was greater. The projectiles after penetrating the plates, retained a greater velocity, and remained entire.

Nine shells of hardened metal were then fired with the same charge and at the same elevation as the weighted shells, loaded with 2.25 lbs. of powder. Three struck the platform. The effects were similar to those of the weighted shells, the projectiles broke up before the bursting charge could explode.

Four steel shells out of nine, with bursting charges of from 3.6 lbs. to 5.4 lbs., fired with charges of 9.94 lbs., at an elevation of 57°,

struck the target. Only one burst, and scattered its fragments beneath the plating.

Some were of opinion that the bursting charge was insufficient, or that the thickness of metal should be reduced, so as to afford a larger internal space, and at the same time a better chance of inflaming the charge by the shock. Others believed the explosion to be due to the shock and the friction of the grains of powder against the sides of the projectile only, and that if the charge did not burst, it was owing to deficient velocity of the projectile at the moment of impact. The heat developed by the blow, reaches immediately to a very slight depth in the thickness of the projectile, and to make it penetrate as far as the powder it would be necessary to reduce the thickness of metal to a degree incompatible with strength, especially when a cheap description of steel is made use of in the manufacture.

The Committee were of the opinion that nothing would ensure bursting but a percussion fuse in the base of the projectile. But this arrangement would only prove advantageous with a large interior charge, and the quality of steel which it is proposed to employ does not admit of greater internal capacity than is possessed by the shells of hardened metal. There is, therefore, no room for researches in this direction.

The Committee concluded that it is simply advisable to abstain from placing the bursting charge in a cartridge in the case of mortar shells, as the velocity on impact of these projectiles is less than that of shells fired point blank against armored surfaces, and there is no fear of their exploding before penetrating the armor.

Further, the ammunition for mortars for coast service should consist of an equal number of shells of steel, and of hardened metal.

One of the members of the committee, Colonel Spitzberg, entered on the minutes his personal opinion that a percussion fuse would be of great advantage in the case of projectiles containing small bursting charges, whether made of hardened metal or of steel; as the effect of mortar fire against the weakest part of a ship would be considerably augmented thereby.

The experiments of Volkovoié-polé with 8-inch shells, furnished with percussion fuse at the base, have already given satisfactory results.

Colonel Spitzberg proposes that the same arrangement should be applied to the shells of the 9-inch mortar whether made of hardened metal or steel.

BOOK NOTICES.

Publications Received.

Official Gazette of the United States Patent Office. Vol. 19, Nos. 5 and 6.

A Lecture on the Improvement of the Danube at Vienna. By Sir Gustave v. Wex. Translated by Maj. G. Weitzel. Washington: Government Printing Office.

Modern Architectural Designs and Details. No. VI. New York: Bicknell & Comstock.

This work continues to afford valuable aid to working architects.

Report of the Board to Recommend a Standard Gauge for Bolts, Nuts and Screw Threads for the United States Navy. Washington: Government Printing Office.

Papers Read before the Pi Eta Society of the Rensselaer Polytechnic Institute. Vol. 2, No. 1. Troy: Lisk & Barnum.

Transactions of the American Institute of Mining Engineers. Vol. VIII. May, 1879 to February, 1880. Easton: Published by the Institute.

Les Principales Applications De l'Electricite. ParE. Hospitalier. Paris: G. Masson. For sale by D. Van Nostrand. Price $3.50.

Only a single chapter of this royal octavo is devoted to Electric Batteries and their applications. The remainder of the work is devoted to Thermo-electric, Electro-dynamic machines, Electric Lights, Telephones, and Microphones.

The illustrations are on a liberal scale and of superior quality.

A Simple Treatise on Heat. By W. Mattieu Williams, F. R. A. S. London: Chatto & Windus. For sale by D. Van Nostrand. Price $1.00.

No modern writer knows better how to write a brief popular treatise which shall at the same time be scientific than Mr. Williams.

He has here presented the common facts learned by observation, and the facts also that have been reached by laborious and skillful experiment.

The proper arrangement of these facts without particular reference to molecular motions constitutes the science of heat as present in this simple treatise.

Sir William Herschel—His Life and Works. By Edward S. Holden. New York: Charles Scribner's Sons. For sale by D. Van Nostrand. Price $1.50.

This brief memoir sets forth with earnestness and enthusiasm the claims of the great astronomer to the regard of scientists of today. The position of the author will cause his estimate of Herschel's attainments, either as a physicist or astronomer, to be received with respect everywhere. The book will prove an acceptable contribution to biographical literature.

Engine-Driving Life. By Michael Reynolds. London: Crosby, Lockwood & Co. For sale by D Van Nostrand. Price $1.

In former times it was the sailor who furnished the dramatic situations for the popular tales. Out of quite an ordinary experience for his profession, the mariner was always ready to supply the demand for truthful accounts of imminent peril, hair-breadth escapes, and safety secured by coolness and presence of mind in the face of great danger.

This little book bears assurance that the sailor can no longer monopolize the situation. Travel by land has its perils as well as travels

by sea ; and for every situation on ship-board requiring instantaneous brave action in which life is risked, the locomotive furnishes an incident to surpass it.

It is a new record of human experience, and is worth reading.

ELEMENTS OF ASTRONOMY. By ROBT. STAWELL BALL, LL. D., F. R. S. Text Book of Science. For sale by D. Van Nostrand. Price $2.25.

This is a popular treatise in so far as that the reader is expected to understand only the elements of Algebra and Geometry for a complete mastery of it. It is intended for beginners, but it is believed by the author that even advanced students may read it, particularly the latter portions, with profit.

The contents include in separate chapters the following topics:

Chap. I.—Astronomical Instruments.
" II.—The Earth.
" III.—The Diurnal Motion of the Heavens.
" IV.—The Sun.
" V.—Motion of the Earth around the Sun
" VI.—The Moon.
" VII.—The Planets.
" VIII.—Comets and Meteors.
" IX.—Universal Gravitation.
" X.—Stars and Nebulæ.
" XI.—Structure of the Sun.
" XII.—Astronomical Constants.

The illustrations are good and abundant.

ODONTORNITHES: A Monograph of the Extinct Toothed Birds of North America. By O. C. Marsh. For sale by D. Van Nostrand. Price $12.00.

This fine quarto is designed for scientific readers only, and will be read with care by paleontologists alone.

The popular mind will experience some pleasure in learning of the exclusive possession by this country of the remains of toothed birds, but lovers of science will regard with admiration the evidence of a high order of attainment in a confrere, and will see nothing to regret in the mechanical execution of this new addition to American scientific literature.

TRAITE DE CHIMIE: By Paul Schützenberger. Paris: Librarie Hachette et Cie. For sale by D. Van Nostrand. Vols. 1 & 2, price $11.20.

Only two volumes of this fine work are as yet published. The complete work will fill six royal octavo volumes. It presents general Chemistry, Chemical Physics and Chemical Technology as inseparable parts of one branch of science.

The illustrations are numerous and of unsurpassed excellence.

The order of arrangement is the one founded on atomicity of the elements.

CHAUFFAGE ET VENTILATION DES LIEUX HABITES. Par P. Planat. Paris: Ducher et Cie. For sale by D. Van Nostrand. Price $10.50.

To know how vast a subject is that of Heating and Ventilation, it is necessary to turn over the leaves of this ponderous volume. Nothing bearing, in any way, upon this subject can have been omitted, and yet nothing seems to have been treated with unnecessary fullness.

All plans and devices are treated with that careful regard for clearness of exposition which is characteristic of the French scientific writers.

RANKINE MEMORIAL VOLUME: with Biographical Sketch. By Professor P. G. Tait. Editor, W. J. Millar, C.E. London: C. Griffin & Co. New York: D. Van Nostrand. Price $10.00.

The volume containing selections from the writings of the late Professor Rankine now before the public, was originally proposed not long after the death of the lamented author of the papers, but from various causes was delayed. We are glad, however, to congratulate the publishers on the appearance of the volume, more especially at a time when the higher and more exact education in scientific principles is being recognized as the foundation of all true knowledge of our physical surroundings.

The loss to scientific and engineering culture through the death of Professor Rankine can only be fully appreciated by those who are most intimately acquainted with him, and who had the privilege of hearing his lectures, or were associated with him in his various pursuits as an engineer and a man of science. Some of these characteristics the editor and biographer have given us in the introduction to the volume, and not the least notable of these was the extreme clearness and precision with which Professor Rankine stated his opinions and the breadth of view which he adopted.

Professor Rankine's Manuals have now been published for a number of years, and have gone through many editions, and are recognized as most valuable compendiums of engineering science quite unique of their kind. They are confessedly hard reading for a great number, especially to those who have not had the privilege of hearing the master himself expound in the lecture room, and were possibly to some extent before their time, as the exact habits of thought required to follow with advantage the teaching of these books could hardly be looked for amongst those actively employed in the every-day routine of the engineering profession. The development of chairs of engineering in our universities, and of classes for the study of mechanics and engineering subjects in our various institutions, during the period since Professor Rankine himself began to lecture, has, however, caused an increased demand for books of a higher class, whilst the growing influential status of the engineer in all the branches of the profession, combined with the various movements at present on foot for the proper organization of technical instruction in the arts, point conclusively forward to the demand for high-class works treating of the principles upon which all such practice must depend.

The present memorial volume contains selections from the various papers which the late professor so profusely supplied to our various scientific and engineering societies, and to journals, and these papers have been selected, as stated by the editor in his preface,

as being "most characteristic of their author in his capacity of a scientific and mathematical inquirer."

The papers range over a period of fully twenty years, and are eminently noticeable for their high scientific value, both as regards the matter treated of and the admirable method of the treatment. The papers number 37 in all, and have been grouped into three great divisions with the object of classifying kindred subjects.

In looking at the bulky volume now issued, and which, after all, contains only a selection from the various contributions of Professor Rankine, we are forcibly impressed with the mental power, energy, and perseverence, required in the author during his term of arduous pursuit of knowledge for the working out of results so profound in their speculations, and so varied in their character; and as we see his features depicted before us in the engraving, which so suitably prefaces the subject matter, we long "for the touch of the vanished hand and the sound of the voice that is still."

To his old students, and to scientific men everywhere, we need not commend the volume now published, as we are sure they will readily appreciate the memorial now offered to one so well known in the scientific world. We think, however, that the publication of such collections of papers has even a higher value, as, in after years, those who are still working in the same fields have in such volume a record of the steps trod by their predecessors, serving at once as an incentive to further investigation and pointing out what has already been accomplished. In the present volume we have also an excellent biographical sketch written by Professor Tait, which, with the editor's preface, containing a carefully prepared abstract of the paper, forms a fitting introduction to this highly important addition to our scientific literature.—*Abstract of a Review in Engineering.*

MISCELLANEOUS.

APPARATUS FOR MEASURING THE COMPARATIVE STRENGTH OF BROKEN STONES.—The French Government, after having made various experiments, have adopted an apparatus for testing the relative toughness and resistance of broken stones suited for macadamizing roads. It consists of two hollow cylinders, mounted on the same shaft, in an inclined position. Into one of these, the material selected for the basis of comparison is introduced; into the other, the material to be tested. The cylinders are slowly turned on their axis for a given time; after which they are emptied of their contents, and the respective quantities of stone reduced to powder are weighed. The ratio of these weights constitutes the coefficient of wear. The relative wears thus determined have been proved to harmonize with the results of wear in the road.

The pieces of stone selected for trial are as nearly uniform in size as is practicable—made to pass through a ring gauge, 6 centimetres, or 2.36 inches in diameter.—*Abstracts Proc. of Civ. Eng.*

TENSILE STRAIN AND ELECTRIC RESISTANCE. Some interesting results showing the connection between the electric resistance of iron wires and their state of strain have been communicated by Mr. W. H. Johnson, B. Sc., to the Manchester Literary and Philosophical Society. The wires were tested for their resistance by means of a Wheatstone balance with reflecting galvanometer of low resistance, and for their tensile stress by an apparatus similar in principle to a steelyard weighing machine. A series of measurements were made upon different varieties of iron wire, beginning with pure iron smelted and worked throughout with charcoal, and ending with highly carbonized steel wire. The results show that charcoal iron has the least electrical resistance, or about one-half that of piano steel; and it is noticeable that the resistance regularly increases as the impurities augment. Annealed steel, which comes about midway between pure charcoal iron and piano wire in the amount of carbon it contains, is also intermediate in point of electrical resistance. Annealing considerably diminishes the electrical resistance of puddled iron wire. The breaking strain and the resistance are also found to increase together in a fairly regular manner. Annealing is found to diminish the resistance of bright steel wire about 1 per cent., while hardening and tempering increase the resistance of the metal to the passage of the electric current. With regard to torsion, the tests show that the electrical resistance is, roughly speaking, inversely proportional to the number of twists in the length of 8 in. The importance of electric conductivity in boiler plates is pointed out by Mr. Johnson in his paper. The heat conductivity of metals is nearly proportionate to their electric conductivity, and, as boiler plates should conduct heat well, they ought also to have a high electric conductivity.

AT a meeting of the Manchester Association of Engineers, a paper was read on the 8th inst., by W. H. Bailey, on "Recent Methods of Testing Portland Cement," in which he described a number of testing machines, and in calling attention to the enormous quantity of cement now used in hydraulic and other engineering works, showed the necessity for the most careful and frequent testing of all cement used on any work.

IN connection with the Ribble Navigation scheme, a meeting of a committee of the Preston Town Council, formed to negotiate with the Ribble Navigation Company, has been held, at which it was decided to carry on negotiations with the company; and it is expected that next session the corporation will be able to obtain an Act of Parliament for the transfer of the stock of the company and the whole undertaking to the corporation.

A TRIAL is about to be made by the Guisbrough-in-Cleveland Local Board of 100 tons of Tees slag bricks made from blast furnace slag, as metalling for the highways instead of whinstone.